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CONVERSATIONS ON CHEMISTRY

PART I GENERAL CHEMISTRY



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CONVERSATIONS ON CHEMISTRY.

FIRST STEPS IN CHEMISTRY.

PART I.

GENERAL CHEMISTRY.

BY

PROF. W. OSTWALD.

AUTHORIZED TRANSLATION

BY

ELIZABETH CATHERINE RAMSAY.

12mo, viii + 250 pages, 46 figures. Cloth, \$1.50.

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BY

W. OSTWALD

Professor of Chemistry in the University of Leipzig

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ELIZABETH CATHERINE RAMSAY

PART I

GENERAL CHEMISTRY

FIRST EDITION, CORRECTED

THIRD THOUSAND

NEW YORK

JOHN WILEY & SONS

LONDON: CHAPMAN & HALL, LIMITED

1911

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Entered at Stationers' Hall.

THE SCIENTIFIC PRESS
ROBERT DRUMMOND AND COMPANY
BROOKLYN, N. Y.

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AUTHOR'S PREFACE.

THE causes which led me to write this work lie partly in the past, partly in the future. The former spring from the feeling of thankfulness with which I even now regard the "Schule der Chemie" of Stöckhardt, whose memory still lingers among us. By a stroke of good fortune this excellent work was the first text-book of chemistry which was placed in my hands, and it influenced the whole of my subsequent activity in science. Owing to the carefully thought-out directness in representing the facts to the pupil, the skill in selecting experiments suitable to the physical and mental powers of the beginner, I have never lost touch with experiment, although I have been chiefly occupied with general questions of science. The request of the publishers, who used to issue this work, that I should write a modern Stöckhardt, was both an honour and an opportunity of paying off an old debt of thankfulness.

So much for the past.

As regards the future, chemistry has undergone during the past century an enormous development, in which Germany has played an important part. Chemical science in Germany has been furthered by the work of thousands of diligent hands and greatly aided by educational institutions which have become a pattern for the whole world, which have brought about a constant interchange between

science and its applications, and which have given an uninterrupted proof of a continued healthy existence. It was almost entirely organic chemistry which developed in the direction of the discovery of new bodies and their systematic arrangement; and even to this day, by far the majority of young chemists, after hurrying through a short course of analysis, are trained in these methods.

But hasty progress has its dangers, and it is the duty of every man who tries to look into the future to give a timely word of warning; for inorganic chemistry was a science before organic chemistry was thought of; moreover, the processes of inorganic chemistry form the basis of chemical technology, on which that of organic compounds is a superstructure.

The cry was first raised in manufacturing circles that the young chemist trained exclusively in organic chemistry was unfit to cope with the solution of general problems; with that reciprocity between science and technology so characteristic of the German race, the teachers of our science have at once grappled with the problem.

Among the many proposals which have been made to escape, in good time, the pressing danger of chemical onesidedness, none appears to me more suitable than the encouragement of the growth which has developed upon the soil of science during the last ten years. I refer to general and physical chemistry. It deals with questions which lie at the base of organic and inorganic, of pure and applied chemistry; it forms a foundation for all real chemical education, and must be regarded as lying at the root of all chemical teaching, especially in its earlier stages.

By writing a series of text-books dealing with different stages of the subject I have tried to bring about the

knowledge of these principles as they at present exist, first among my colleagues in science, and next among students of chemistry.

The necessity of repeatedly revising the matter of these books, as well as daily experience in teaching, led to my early conviction that the very first steps of a young pupil must point in this direction; I also gained assurance that such an introduction was possible, and this book is the result of my efforts.

I must not omit to mention that it forms the first introductory volume, and that it will be followed as soon as possible by a second of about equal length, in which the system will be more developed.

I have chosen the form of dialogue, because after several attempts it appeared to me the most suitable; moreover, I have come to the conclusion that it occupies no more space than an ordinary description, while the impression it makes is much more penetrating and lively. I venture to hope that it will be found that it is at the same time the result of a varied experience in teaching, and not an accidental choice.

W. OSTWALD.

LEIPZIG, 1903.

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CONVERSATIONS IN CHEMISTRY.

1. SUBSTANCES.

Master. To-day we commence something quite new; you shall begin to learn chemistry.

Pupil. What is chemistry?

M. Chemistry is a branch of natural science. You have already learned something about animals and plants and know that the study of animals is called zoology, and that of plants botany.

P. Then does chemistry teach about stones?

M. No, that is called mineralogy. Mineralogy is not the study of stones alone, but of many other things which are found in the earth, such as phosphorus, gold, or coal. But all these things, too, belong to chemistry. And other things, like sugar, glass, iron, which are not found in the earth, but are artificially obtained from other substances, are also the subjects of chemistry. Chemistry is the study of all kinds of substances, whether artificial or natural.

P. Then does chemistry deal with trees?

M. No, for a tree is not a substance.

P. But it is wood, and wood is a substance.

M. Yes, but a tree consists of more than wood, for its leaves and fruit are not made of wood, but of other sub-

stances. All such substances taken alone belong to chemistry; but to get each alone, the tree must be destroyed.

P. But what do you mean by a substance?

M. That is a long story. Let me see if you don't know it yourself, though you can't put it into words. What is this?

P. I think it is sugar.

M. Why?

P. Well, the sugar in the sugar-basin looks just like it. Let me taste it—yes, it's sugar, for it's sweet.

M. Do you know another way by which you can tell sugar?

P. Yes, it makes your fingers sticky; so does this.

M. You can tell sugar, then, when some one puts it in your hand and asks you if it is sugar. And you knew it, first by its appearance, then by its taste, and lastly by its stickiness. These signs by which you recognize a substance are called "properties"; you know sugar by its properties. Sugar is a substance; one can tell substances by their properties. Do you think you could use all the properties of a substance in order to recognize it?

P. Yes, if I knew them.

M. We will just see. Is there only one sort of sugar? No, you know loaf sugar, which is in large lumps, and sifted sugar, which is a powder, like sand. Both are sugar, because when you pound up loaf sugar it becomes like sifted sugar.

P. Yes: then they are both the same.

M. Both are the same substance, sugar, but one of its properties has been changed. The shape of a thing is also one of its properties; if you like you can change its shape, yet the stuff of which it consists remains the same.

This also applies to quantity. Whether the sugar-basin is full or almost empty, what is in it is always sugar. So you see form and quantity do not belong to the properties by which you recognize a substance. Is sugar hot or cold?

P. I don't know; it may be either.

M. Quite right. So neither heat nor cold is a property by which you can tell a substance.

P. No, of course you can't; for you can make sugar as coarse or as fine, or as hot or cold as you wish.

M. Now we have got to the bottom of it. Among the properties of a thing there are some which cannot be altered. You will always find that sugar tastes sweet, and that it makes your fingers sticky. But you can change its size and form, and you can heat it if you like. Every definite substance has its distinct unchangeable properties, and a thing bears the name of this substance when it has these fixed unchangeable properties, quite independently of whether it is warm or cold, large or small, or how its changeable properties may vary.

A thing has often another name, according to its use or its shape, different from that of the substance it is made of. Then it is said to consist of this particular substance.

P. I don't quite understand that.

M. What's this? what's that?

P. A knitting-needle and a pair of scissors.

M. Are knitting-needles and scissors substances?

P. I'm not sure— No, I think not.

M. If you wish to know, you have only to ask: What does the thing consist of, or what is it made of? Then you generally come at the name of the substance. What are knitting-needles and scissors made of?

P. Of iron. Then is iron a substance?

M. Certainly, for a piece of iron is called iron, whether it is large or small, hot or cold.

P. Then paper is a substance, because a book is made of paper, and wood is a substance, because the table is made of wood, and bricks are a substance, because houses are made of bricks.

M. The first two examples are right, but not the last. Does a brick remain a brick when it is broken up and powdered? No: the name "brick" is given to a thing that has a definite shape, so it can't be a stuff. But what are bricks made of?

P. They're made of clay.

M. Is clay a substance?

P. Yes—no—yes, it is, because if you break up clay it still remains clay.

M. Quite right. You can often help yourself out like that when you are in doubt. First you must ask: What is the thing made of? And when you have answered that, you must go further, and ask: Does it remain the same when I break it up? and if you can say Yes, then it is a substance.

P. Then there are many, many different kinds of substances?

M. Yes, certainly there are many; far more substances than you can name. And chemistry has to do with all such substances.

P. Oh, then I shall never be able to learn all about chemistry—it's hopeless. I'd rather not begin.

M. Do you know the forest near here?

P. Yes, rather: you could put me where you like in it, and I should always know where I was.

M. But you don't know every single tree in it? How can you help being lost?

P. But I know the paths.

M. Now, look here, that is what we are going to do with chemistry. We will not learn about every single substance that there is, but we will learn the paths which divide up the countless substances into different groups, and by help of which we can find our way from one place to another.

When you know the principal paths you will know where you are in chemistry, and afterwards you can leave the chief paths, and find out more about the byways. And you will see that learning chemistry is just as good fun as walking in a wood.

2. PROPERTIES.

M. Let me hear what you learned last time.

P. Chemistry is the study of substances, and substances are what things consist of.

M. The first part of your answer is right, but the second is not quite right. A piece of music consists of sounds; but are sounds substances?

P. Yes; for you can call the sounds music is made of, substances.

M. Yes, in a figurative sense you can. But in the language of science the name "substance" is limited to things that have weight.

P. What right has any one to limit the meaning of a name?

M. The right of necessity. In the language of ordinary life people are not generally very careful of the meaning of words, as you showed yourself just now. In science, however, we have to try to be as accurate as we can,

and that is why we have to give every-day words an exact and accurate meaning. These meanings are made as like as possible to those which they ordinarily have, and really mean the same thing to all intents and purposes, only the boundary-line of use and meaning is more sharply drawn.

Most things which are generally known as substances are called the same in chemistry; but *no* things that have no weight. Now correct the last part of your sentence: "Substances are everything" . . .

P. A substance is anything of which a weighable thing consists. Yes, but I don't know yet what a substance really is.

M. What do you mean?

P. I know quite well what things to call substances, but that isn't all. It doesn't tell me any more than I knew before. I know nothing about the nature of a substance yet.

M. How should you know it? By giving a word a distinct scientific use, or defining a word, nothing more has happened than that I drew a circle round it so as to limit the meaning of the word within certain bounds. We have made a fence round our forest; but, of course, that doesn't teach us to know it. As you learn the properties of the various substances, you will also learn their nature, and that will give you plenty to do.

P. But when I know all the properties of a substance, I'll only know—how can I put it?—the outside of it. I can't get through to its inner nature.

M. Don't you remember that there are different sorts of properties? What are they?

P. You mean what we spoke of yesterday? There are changeable and unchangeable properties.

M. And which help you to recognize the substance?

P. The unchangeable ones.

M. There now, you've found what you want. The unchangeable properties of a substance can't be taken away; when they aren't there, the substance isn't there either. These properties make the nature of the substance.

P. But that is only its properties. What I want to know is: What lies at the bottom of all its properties?

M. You want to know what remains when you think all the properties of a substance are taken away. Now, just think, if you took away all the properties of a piece of sugar, its colour, form, hardness, weight, taste, etc., what would remain?

P. I don't know.

M. Nothing would remain. Because it is only by the properties I can tell that something is there; if no properties are present, there is nothing there that I can speak about. You must get rid of the idea that there is anything higher or more real to be found in a thing than its properties. Long ago, when science was little advanced, people thought something like that, and there are remains of it in ordinary speech, so that one unconsciously gets these ideas through the use of ordinary expressions. But once you recognize this error you can avoid it.

P. I see you are quite right, but I'm afraid it will take me a long time to get rid of the other idea.

M. You will be convinced when you have learned more chemistry that we really only speak of the properties of a stuff, and never of its "*nature*." And you will forget your mistake later.—Anyhow, this talk has had its use, for now you see clearly that everything depends on our determining and knowing properties. Tell me

some properties which help you to recognize a substance. For example, what is the difference between silver, gold, and copper?

P. The colour; silver is white, gold yellow, and copper red.

M. Does colour belong to the changeable or to the unchangeable properties of a substance?

P. Generally to the unchangeable, I should think.

M. Why are you so uncertain about it?

P. I am not quite sure: the colours of gold and silver are unchangeable, but old copper doesn't look red, but dark, and often green.

M. Have you ever looked carefully at a piece of copper that has become green? Is the copper green through and through?

P. I think not; no, you can scratch off the green, and there is red copper underneath.

M. Quite right; and the green is, in other ways, not like copper; it is not tough like metal, but crumbly like earth. The fact is that another substance, green in colour, has been found on the copper, that was not there before, and it has only covered up the red copper, just as the yellow wood of the window-frame is covered with white paint.

P. How does the green come on the copper?

M. It is formed from the copper: you will learn later exactly how it comes. At first we will go back to the question of colours. Now we must take colour as an unchangeable property, by which we can recognize a substance. Only we must take care not to mistake the colour of a chance layer on the surface for the colour of the substance itself. We see that best if we break it into pieces, and so expose the inner part. Let us try it.

Look what I have here. It is a blue substance, which is called copper sulphate.

P. Oh, please don't break it up, it has such a lovely shape, just like a cut jewel.

M. Those shapes are called crystals; they are not made by cutting, but form themselves without our help.

P. May I see that?

M. You will soon learn for yourself how to form crystals. I have a great many more, and we can quite well use this one, if we are going to learn anything by it. There, I have broken it: look closely if the blue colour of this stuff is its own.

P. Yes, it is, because the stuff is just as bright a blue inside as outside.

M. Now we will break it up still smaller in this thick little porcelain dish, which is called a mortar. For that we will use this thick rod, which is called a pestle (Fig. 1).

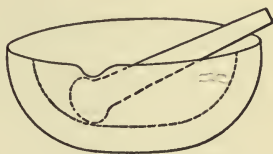


FIG. 1.

P. Why are you giving yourself so much unnecessary bother? We know already what will happen.

M. Look at it carefully. When you have drawn a conclusion you must test it properly, or else you won't know that you haven't overlooked or forgotten something. What do you see?

P. The pieces don't seem to be quite so blue inside as the crystal was outside, for the broken bits seem to get lighter coloured, and now the powder is quite pale blue, almost white. I can't understand that, because before, the big bits looked quite dark blue. Perhaps something has been rubbed off from the mortar?

M. No, porcelain is hard, and is not affected by rubbing. But look at these broken bits of blue glass. Here it is even darker than the copper sulphate was, and here it is almost colourless, yet it is the same blue glass.

P. That is quite easy to explain: the glass is far thicker in one part than in the other. Ah, now I understand; the little pieces of copper sulphate are just as light blue as the glass in their thin parts, and the large pieces dark like the thick glass.

M. Right. When light penetrates a piece of the blue substance it gets reflected again and again inside, till it can come out somewhere, so that the further in it has to penetrate the bluer it becomes. That is why the larger or thicker pieces are darker than the smaller. In the same way the main mass of the sea is dark blue or green, and the small quantities of broken-up water seen on the foam of the waves or in the track of a ship look quite white. That is why, when you are talking of the colour of a substance, you must mention at once whether you are thinking of it in a state of powder or in big lumps. Generally, when we give the colour of a thing in chemistry, we describe its colour as seen when it has been artificially prepared. A great deal still remains to be said on the question of colour, but we have had enough for to-day.

3. SUBSTANCES AND MIXTURES.

M. Go over what you learned yesterday.

P. Substances are known by their properties. One of these properties is colour. This looks different, however, according as the substance is in large or small pieces.

M. Right. Do you know this stone? It is called granite. What is its colour?

P. Grey, and reddish, and black.

M. Why do you name several colours?

P. There are several in the stone; there are grey, and red, and black bits. You can't say that it has any one colour.

M. Is granite a substance?

P. Of course; because all sorts of things are made of granite, for example, the street pavements. And a small piece of granite is still granite.

M. Let us see. Now, just imagine granite crushed into such small pieces that every separate piece is either black, red, or grey. Then we put all the grey pieces in a heap together, and the same with the red and the black. Would you call each of the three heaps granite, or only one, and which?

P. Perhaps the red. No, that wouldn't do. Granite is only granite when it is all together.

M. Quite right. Could you do the same with a piece of sugar, and how many heaps would you have then?

P. No, it wouldn't work with sugar. Sugar always remains the same.

M. Right again. Now, notice well, you have discovered a very important difference. Substances like granite, which can be divided up into different heaps after they have been broken up, are called mixtures. Those where it is not possible, as with sugar, are of the same kind through and through; we call them homogeneous. In chemistry we only concern ourselves with homogeneous substances.

P. Why with these only?

M. Because the number of the others is endless. Just

think: You have two different homogeneous substances. Then you can make innumerable mixtures according to the proportions in which you mix them. If we had to take note of every single mixture, we should never come to an end.

P. But after all they are something; we can't leave them out.

M. Very good. You are quite right. But we don't need to know each mixture separately, and this is true for the following reasons: When we bring together two homogeneous substances into a mixture, all the properties of the mixture are such as can be calculated from the properties of the two separate substances, according to the proportion in which they are mixed. For instance: A mixed colour is the result of the simultaneous and separate action of the single colours of which it is made; the mixing of colours in painting depends on this. For this reason we needn't examine very closely into the properties of mixtures.

P. Please explain that more clearly.

M. When a shopman has marked a yard of material at a certain price, he doesn't need to write down how much a half- or a quarter-yard costs; and so you can easily find out the properties of the mixtures from those of the ingredients; and you don't need to look out and write down those of all possible mixtures. Everything that can be asked about a mixture can be answered by calculation if you know its ingredients and their relative amounts. Our silver money, for example, consists of $\frac{34}{37}$ of silver and $\frac{3}{37}$ of copper, and the value of a pound of this metal is made up of $\frac{34}{37}$ of the value of a pound of silver and $\frac{3}{37}$ of the value of a pound of copper.

P. I see that. But I can't always tell if it is really a

mixture. When I take my paint-box and mix blue and yellow, green appears, not a mixture of blue and yellow.

M. That is only because the grains of colour are too small for you to recognize singly when they are near each other. If you looked at the mixture through a microscope, you would see the blue grains beside and on top of the yellow ones. Blue and yellow glass laid over each other make green. Therefore when the light from a yellow grain goes through blue, or vice versa, it becomes green.

P. But supposing both stuffs were white, then I couldn't recognize them together even under a microscope, and I couldn't tell whether it was a mixture or not.

M. If I took a mixed spoonful of sugar and white sand, then I certainly couldn't see that there were two things in the mixture. But when I pour sugar into water, what happens then?

P. It dissolves, and later the water becomes quite clear again, and tastes sweet.

M. And what happens to sand?

P. It makes the water cloudy.

M. And doesn't make it sweet. Now, if I pour my mixture of sugar and sand into water, the water will become cloudy, and sweet like sugar. So I can tell them both together.

P. Yes, it is so.

M. Why is it so? Now, I will tell you. Colours are not the only properties which substances possess, and by which they can be recognized and distinguished. The behaviour with water is a special property, and this is different with sugar and sand, even though the colours are the same. Therefore when you want to distinguish between a great many different substances, you must

know not only one or two, but a great many of their properties, so as always to find out a difference even though other properties seem the same. That is why so many different properties of substances are examined and described in chemistry.

Now for another question. Looking at the ingredients of granite, we might think that we could separate them by their colour, so that we had them in different portions. Do you think that you could in any way separate the mixture of sand and sugar?

P. It ought to be possible, but I don't know how.

M. Just look at the glass in which I have stirred up the mixture with water. Now, the sand has sunk to the bottom, and the sugar is dissolved in the water.

P. Yes, now I see; you only need to pour off the water with the sugar, and the sand will be left behind in the glass.

M. Will they both be *completely* separated then?

P. No, you can't pour out *all* the water. The sand will be wet, and some sugar will still be in the water.

M. Now, attend and see how it is possible to do it. I have here a round piece of a particular sort of paper, which is called filter-paper. It is something like blotting-paper, as it sucks up water, only it is made of a purer and firmer substance. I fold the paper in half, and then again in half, and pull it apart so that a sort of little trumpet is made, which is quite plain on one side, and on the other has three layers of paper. That is called a filter. I put my filter in a glass funnel and wet it with water. Now I can press the filter on to the sides of the funnel so that it quite covers it. The funnel is now put in a stand and a glass placed under it (Fig. 2).

P. What is the good of all this?

M. To separate the sand entirely from the sugar. If I pour the mixture of sand and sugary water into the filter,

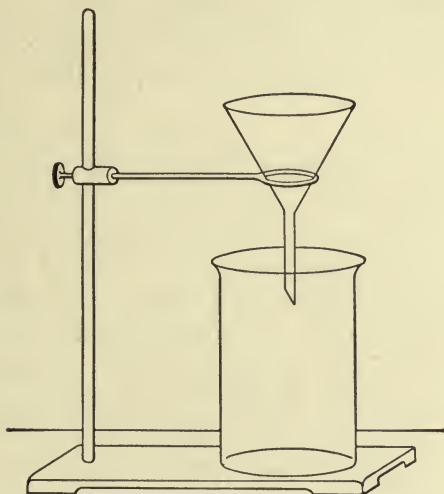


FIG. 2.

the water will come through and the sand remain in the filter.

P. But the sand is still wet and some sugar is still there.

M. That we will soon wash out. I only need to pour some pure water into the filter, and this will run through and take the sugary water with it. Also, to rinse the last grains of sand that remain in the glass into the filter, I use fresh water. In case it wasn't completely through the first time, I wait till the water has run through, and repeat the rinsing out several times. So now we are ready. When the filter with the sand is quite dry, then we have completely separated it from the sugar.

P. But how are we going to get the sugar?

M. We shall get that to-morrow. I pour the water that has run through the filter into a flat china dish, or a plate, and place it on the warm stove.

P. Why?

M. What does water do when you put it on a warm stove?

P. It dries up.

M. Yes, it evaporates, it changes into water vapour, which disappears in the air, and nothing is left in the dish. Does sugar do that, too? Does it become less when it is on a warm stove?

P. No, it stays there till some one eats it up.

M. Quite right. If I put my water which contains the sugar in a warm place, the water will evaporate, but the sugar will stay behind, and when all the water is evaporated, only the sugar remains in the dish. In this way we shall at last have completely separated our mixture of sugar and sand.

P. I wonder what the sugar will look like to-morrow. At present you can't see it a bit, for the water is quite clear, and to-morrow it ought to be there still.

4. SOLUTIONS.

P. Is the sugar there?

M. Here is the dish. Look at it.

P. Yes, I can see a white heap that looks like sugar. There is still some wet, though.

M. That is the rest of the water which remains with the sugar, and only goes away slowly. A great deal of sugar is dissolved there, and the fluid is much less mobile

than pure water, and the water takes far longer to evaporate.

P. But it hasn't come out in powder as we put it in.

M. No, it has appeared in the form of crystals. The crystals in the dish are not large, neither distinct nor beautiful. But I have another sort of sugar here; do you know it?

P. Yes, it is sugar candy.

M. Quite right; this kind of sugar candy is generally made this way. You dissolve it in warm water and let it slowly separate out or crystallize. Only look carefully at the sugar candy; every piece is a crystal.

P. Yes, now I recognize everywhere the smooth, even sides. Is ordinary sugar not made of crystals?

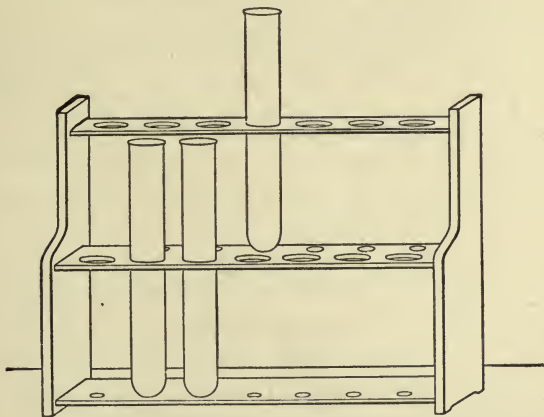


FIG. 3.

M. Certainly, only the crystals are far smaller. Here is a magnifying-glass, a lens. Just look through it at the sugar in the sugar-basin.

P. It looks like sugar candy.

M. Loaf sugar also consists of crystals, but they are so grown together that you cannot easily recognize them. All this sugar is separated from solutions, and therefore it is always crystalline; that means it is made of more or less distinctly developed crystals.

P. Are crystals always left when you let a solution evaporate?

M. In most cases. But to get crystals you needn't always let a solution evaporate; there are many other ways, one of which I will show you immediately. Here I have a glass with the copper sulphate we used lately. If I put some with water and shake it, it will dissolve, and the water will become blue (Fig. 3).

P. Why do you do that in this little glass tube?

M. You will soon see why. A chemist uses these little tubes for most of his experiments, as long as he is not working with great quantities, and for that reason they are called test-tubes. Now I light my spirit lamp and heat the water with the copper sulphate (Fig. 4).

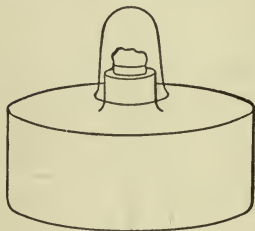


FIG. 4.

P. Take care, the glass will crack! How extraordinary! it hasn't broken.

M. This sort of glass doesn't break if you handle it properly. Now look at the contents; before there was copper sulphate with the blue water; now it has vanished and the solution is a darker blue. I can put more copper sulphate in now, and it will also dissolve. But if I add more and more, finally I can bring the solution to the boil, and the remainder stays in the same condition. Now I add some more water to it and heat

it up again, and it all dissolves. We will now put the clear liquid aside.

P. But why didn't the test-tube break before? Glass cracks when you heat it.

M. Not always. You know that you make glass by melting it, and to do that it must be very hot; every vessel or piece of glass has been made very hot, and yet has not cracked.

P. Yes, but mother scolded me the other day because I had poured hot water into a glass, and it had broken.

M. That is quite true. Here is a contradiction which we must try to unravel. In what other ways can you crack glass?

P. By hitting or crushing it.

M. Yes, when you want to try to make the glass a different shape and at the same time try to strain different parts differently. Can heat also have an effect on the form of glass?

P. Yes, heat causes all bodies to expand.

M. Quite right. Then a hot glass will be rather larger than a cold one. Have you ever seen that?

P. No; it is so little that you can't see it.

M. All the same I will show you. I have here a fairly long glass tube. I fasten it with one end in a stand, so that it is horizontal, and put at the free end a measured ruler. Now notice the line where the end is pointing. So that you may see it better, I shall stick on a black needle with wax. Now I bring my lamp under the tube so as to heat it. What do you see?

P. The end first rises, and then goes slowly down again (Fig. 5). Extraordinary!

M. Why are you so astonished?

P. I thought the needle would go forward, because

as the heat makes the glass tube expand it must get longer.

M. Instead of that it becomes crooked, and bends upward. How, I will explain to you.

P. Wait a moment; I know it myself. The lower part of the tube where the flame hits it has become hotter than the upper part, and so it has expanded more below than above, and has become bent.

M. Right; and afterwards the upper part got hot also,

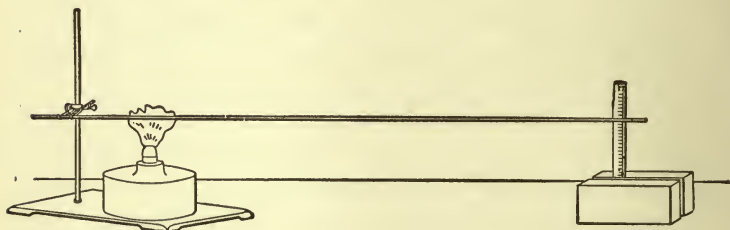


FIG. 5.

and bent itself straight again. Then glass is slightly bendable. But if I bend it too roughly—

P. It breaks.

M. Now you can see why a glass breaks with heat. When you heat it unequally it bends, and when this happens too quickly, it breaks. But if the glass is equally warmed this doesn't happen. The hot water warmed your glass in the inside while it was quite cold outside, and that is why it cracked.

P. But your tube was cold inside when you put it in the flame and heated the outside of it. Why didn't it crack too?

M. Because it is made of very thin glass. The heat passed quickly through the whole glass. You can also

bend thin glass far more than thick before it cracks. That is why all chemical glass apparatus needed for heating purposes is made of thin glass, and care is taken that it is not too quickly or unevenly heated, so that the warmth may spread itself equally over the whole glass. But now we will look how our copper sulphate solution is getting on, that in the mean time has become cold.

P. There is solid copper sulphate again in the glass.

M. I will pour the liquid part in another glass, and take out the hard part with a glass rod. To dry it, I lay it on a piece of filter-paper, that will suck up the liquid. Watch it carefully. What do you see?

P. There are crystals again.

M. Yes; these crystals have not come because the solution is dried up, but because it has cooled.

P. Please explain that to me.

M. If you take a certain amount of water and dissolve copper sulphate in it, can you dissolve as much copper sulphate as you wish?

P. No; after a time it won't dissolve any more.

M. Right. A given amount of water can dissolve only a given amount of another substance. Such a solution is called "saturated." If, however, you warm such a solution, then it can dissolve more. But when you cool it again, the solution cannot contain the extra amount it has taken, and this separates itself in a solid form and takes the shape of crystals.

P. That is just the same as after evaporation; for the water went away, and there was no more there for the substance to keep in solution.

M. Quite so. Whenever there is more substance than a saturated solution can hold, it separates itself in solid form. Later on we will learn another condition

that must be fulfilled by this. But I haven't yet asked you what you learned yesterday.

P. Yesterday we talked about mixtures and homogeneous substances. Mixtures consist of different substances.

M. And how can mixtures be recognized and separated?

P. By the constituents having different properties; for example, we can pick them out if they have different colours, or one will dissolve in water and the other remain behind.

M. Yes, if the other doesn't also dissolve in water. But the solutions that are produced, are they mixtures or homogeneous substances?

P. Mixtures.

M. Why?

P. Because you can put them together out of different substances, and again you can divide them up into their ingredients.

M. That is right so far; but have solutions like other mixtures the same properties as the ingredients before they are mixed?

P. Yes, the solution of copper sulphate is blue like the copper sulphate and a solution of sugar tastes sweet like sugar.

M. Copper sulphate and sugar are solid bodies, but their solutions are liquid like water. If you take another solid body like sand, and stir it up with water, it will make a thick mixture, and not a solution.

P. Yes, there is a difference there. But perhaps the sugar gets divided up into such small pieces that they can neither be seen nor felt.

M. You may believe it, but you cannot prove it. For

when you look at a solution even through the strongest microscope, you don't see any separate particles.

P. But perhaps the particles are still smaller?

M. It is useless to speak about it any longer, as we can't decide it.

P. There is something special about solutions, then, which can be distinguished from ordinary mixtures?

M. Yes; solutions are homogeneous mixtures.

5. MELTING AND FREEZING.

M. What did we speak about yesterday?

P. About solutions, but I didn't quite grasp it all.

M. What is the difficulty?

P. That out of a solid substance or a liquid a real liquid is made.

M. Just think for a minute if you can't make liquids out of solid substances in any other way.

P. Oh yes, when ice or snow melts.

M. Does that only happen with ice or snow, or can other solid substances melt?

P. Yes; on New Year's eve we melted lead.

M. Through warming or heating you can make solid things melt, or turn them into liquid. And when the liquid is cooled?

P. It becomes solid again.

M. Then we can change ice into water, and water into ice, if we warm the ice, or cool the water. At what temperature will ice become liquid?

P. At 0° .

M. And when does water freeze to ice?

P. Again at 0° .

M. Does the ice become liquid when it is warmed to 0° ?

P. It ought to.

M. You have forgotten what you learned about that in your Physics lessons. We will just try it for ourselves. I have here a thermometer. This sort is made out of a narrow glass tube, with a bulb at the bottom containing mercury (Fig. 6). As mercury expands with heat much quicker than glass, it rises higher in the tube, and the higher the temperature is, the higher it rises. A row of equidistant strokes, with numbers, a scale, makes it possible to read the height of the mercury, and consequently the temperature. I now dip the bulb of the thermometer into the crushed ice here in the beaker. In a short time it sets itself opposite the stroke with the mark 0° .



P. Why does the mercury stand at the 0° ?

M. The thermometer-maker arranged that. When he had the instrument so far ready that only the scale remained to be put on, he put it in melting ice, and marked the place where the mercury was. After that he placed the scale so that the zero came exactly on this place.

P. Then there is no heat there.

M. No, it is a temperature that we have called 0° . It is quite an arbitrary choice, because you know that in winter the temperature falls far below zero. The lowest temperature that has been reached so far lies about 260° below 0° .

P. Why did they hit upon this choice?

M. That you will soon see. I surround the beaker with my hands, and try to warm it. Look at the thermometer.

P. It is still at 0° .

M. Now I pour some water out of the bottle that has stood in the room for this purpose. About what temperature is this water?

P. In a room it should always be about 17° or 18° . The water will be about the same.

M. Look at the thermometer.

P. It is at 5° .

M. The warm water has raised the temperature then. Now stir it carefully round.

P. Now the thermometer is getting lower; now it is again at 0° and is remaining there. How is that? The room is warmer, and the thermometer ought to rise.

M. When ice and water are together, the temperature always remains at 0° as long as both are present. If you try to raise the temperature by adding heat, so much ice melts as to use up the whole added heat. If you take heat away, so much water freezes as to replace the heat removed.

P. Is heat made when water freezes?

M. Certainly; when water freezes to ice, exactly the same amount of heat is formed as is used when the ice is melted again.

P. How is it that it is exactly the same?

M. Just suppose for a moment that the two quantities were different; suppose that on freezing, the resulting heat was represented by the number 80, and on melting only 60 was used. If we freeze water, and then let the ice melt, it is exactly the same at the end as at the beginning; but of the heat, 80 parts have been produced, and only 60 used, so that 20 remain over. Now this can be done as often as you like, so that you could produce any quantity of heat from nothing. *But that is not possible,*

and therefore in melting, exactly as much heat is used as was given out on freezing.

P. Is it quite impossible to make heat out of nothing? Rubbing makes heat.

M. But not for nothing. To rub, you must work, and you cannot create work out of nothing. But let us leave this subject, for I will explain to you later what a quantity of heat is, and how it is measured. We will go back to our water and ice. You saw that when both were together, the thermometer always remained at a particular temperature, which is generally called 0° . Therefore there is quite a definite temperature when solid ice changes into liquid water, or melts. Now, do you think that there is always a particular temperature when a solid substance melts?

P. There must be something of the sort, as lead is easily melted, and silver is difficult to melt.

M. Now we come to a general law, that every substance melts at a particular temperature and freezes at the same temperature. The melting-point and freezing-point of a substance are always the same. It is that temperature at which the solid substance and the liquid substance can exist together, and at which heat added or removed is used only in changing the liquid or the solid from one into the other. The melting-point then is as much a property as its colour or solubility.

P. Who made this law?

M. The name law is only used figuratively. People found that it was the case with substances, and have consequently compared them with obedient pupils, who always do what they are told. In science, people understand by a law something that applies to many things, and can be expressed in a general form.

P. Are there many laws like that?

M. Yes, a great many. To know such laws makes the task of noticing and using individual facts much easier.

P. Please explain that more distinctly.

M. Let us take the law that a mixture of water and ice has always a definite temperature. If a thermometer-maker in London has made his thermometer so that a mixture of ice and water shows a temperature of 0° , he can be perfectly sure that wherever in the whole world ice and water are brought together the temperature will be 0° . Were this not the case he couldn't sell a thermometer, and we couldn't use a bought one for our purpose.

P. It is really nice of the law to help the thermometer-maker so much.

M. A law of nature is not a being who either does something, or leaves it undone. People have discovered that ice and water together have always the same temperature. Therefore, in this case, the thermometer-maker is placed in such a position that he can always make generally useful thermometers. But with one point, the point of zero, the thermometer is not finished; all the other lines have to be marked.

P. Aren't these just ordinary millimetres, like a ruler?

M. No, that wouldn't work. For sometimes the tube is narrow and sometimes wider, sometimes the bulb with the mercury is large, sometimes smaller. The mercury would then rise to different heights if the thermometers were equally warmed, and so they wouldn't agree.

P. That is true. Then you must warm all thermometers the same amount, and mark the place of the mercury, and then put on equal numbers of marks till you come to 0° .

M. Good. To what temperature should you heat them?

P. To any.

M. That wouldn't be right. Of course all thermometers would agree that had been made at the same time, but at another place no one would know what the common temperature was where the top mark was made.

P. Then I can't think of anything better.

M. It would help us if we could only find a temperature that was as easy and certain as the ice-point.

P. Ah, now I remember; it is the boiling-point of water.

M. Yes, it is the temperature at which water boils. That is what we shall speak about to-morrow.

6. BOILING AND EVAPORATION.

M. What did you learn yesterday?

P. I learned that melting ice always shows the same temperature, which never alters whether much or little water or ice is present.

M. And what about the freezing of water?

P. That shows the same temperature. But what happens when all the water is frozen?

• *M.* Then we have only ice, and this we can cool as much as we like. In the same way, when we melt ice all the ice becomes liquid. . . .

P. Then we have only water, and this we can warm as much as we like.

M. That is nearly right, but you jumped to a too rapid conclusion, because it doesn't hold in all cases. We will speak about this shortly. But first let us go over again what we spoke about. What is the condition that gives the temperature of 0° ? Try to explain this as quickly and generally as possible.

P. Let me think a minute. Ice is at 0° when it melts, and water when it freezes. But when ice is melted, or water is frozen, it isn't at 0° any longer. There must be ice in water, or water along with the ice. Oh, now I know; when ice and water are together, then the temperature is at 0° .

M. Right; that is the condition. Can you see exactly why this condition must be fulfilled?

P. It seems to me it must be quite simple, only I can't get it out.

M. It is really quite simple. What happens when you try to warm a mixture of ice and water?

P. You explained that to me yesterday. It only melts some ice, and that uses up the heat that has been put in.

M. And when you try to cool it?

P. Then some of the water freezes to ice, and gives . . .

M. And gives out exactly the same amount of heat as has been taken away. You see the thing is like the height of water in a pond that always remains at the same level. If you take water away, more flows in from the spring; if you pour water in, it runs over the dam, and the height of the water is still the same.

P. I understood that, but I haven't got it quite clear yet. Does a lot of water with a little ice give the same temperature as a lot of ice with a little water?

M. You have not been attending. We learned all this yesterday as a law of nature; that is to say, as a thing that is always the same.

P. Oh, now I remember; now I see it all. Why, it is ridiculously easy; I thought it would be far more difficult.

M. That will often happen. When you have got a thing quite clear, it always seems very easy. But the getting it clear is not always so simple and easy. But

now let us go back to my first remark. Can you really heat water without ice as much as you want? What happens when I put water in a pot over the fire?

P. First it will get hot, and then it will begin to boil.

M. Right. We will make the experiment. I have here a flask made of thin glass which I can put over the flame without its cracking. In it is some water, and I shall put it over a tripod which stands above my lamp (Fig. 7).

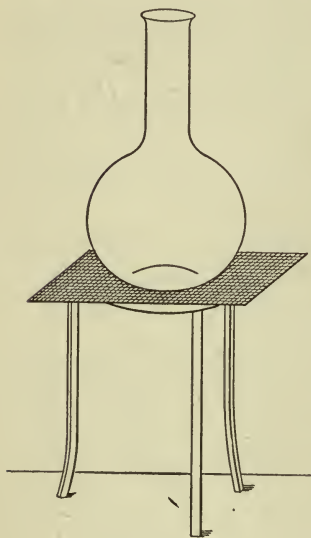


FIG. 7.

P. Why is that wire gauze on the tripod?

M. For one thing, so that I can put large and small vessels on it. Again, the metal spreads the heat of the flame, and prevents the glass from breaking so easily if it is a little thicker. Now I put my thermometer in the water.

P. Do you see? The water is getting warmer.

M. Wait a bit.

P. Now the water is boiling, and the mercury has risen quite high; it is already at 100° . Now it will soon fill the whole thermometer. What will happen when the mercury has no more room to expand?

M. The thermometer will break, for it exerts very strong pressure.

P. Then take the lamp away at once.

M. Look at the thermometer first.

P. It is still at 100° .

M. And will stay there as long as you like. I am making the flame bigger. What do you see?

P. The water is boiling harder.

M. And the thermometer?

P. That is still at 100° . Oh, now I am beginning to notice something. It seems to be exactly the same here as with the melting.

M. Quite right. Now try to trace the resemblance. Then the temperature was unchangeable when two things, ice and water, were together. What is it here?

P. There is water here too, but what is the second? Wait a bit, I've got it now; it is steam. Is that right?

M. Yes. When I supply heat by means of a flame, it doesn't heat the water any more, but changes it . . .

P. Into steam!

M. Now we must reverse this relation. We had the same temperature before, whether we started with water or with ice; now . . .

P. Now we must get the same temperature whether we start with water or steam. We have got the one when we started with water, but how do we get the other? We must take a vessel with steam, and try to cool it. That isn't easy to do; we must have a boiler for it.

M. We can do it in a much easier way. Look, I take the thermometer out, and let the water boil quickly for a minute or two. The thermometer has now cooled a little, and it has fallen to under 50° . Now I put it again into the flask; not into the boiling water, however, but hold it above in the upper part of the flask. What do you see?

P. Water is dropping from the thermometer. How did it get there? I know; the steam in the upper part of the flask has condensed on the cold thermometer.

M. Right. Read the temperature.

P. It is at 100° again.

M. Now we have made the experiment for which you wanted a boiler. The upper part of the flask contains steam, which rushes upwards and makes clouds outside. By the cold of the thermometer a part of the steam is made into liquid water, and also in the upper part of the flask too. You have thus steam and water together. Steam condenses to water on the thermometer till the lost heat is supplied again, and the temperature has risen to 100° .

P. Is there really steam in the upper part of the flask? It is quite clear.

M. Steam is as transparent as air.

P. Is that so? I thought steam was always misty and untransparent. When a steam-engine blows out steam, you see it like a thick white cloud, and in the same way the clouds in the sky are steam.

M. No, what you see isn't steam, but liquid water in very small drops that have been made out of steam by cooling. If you could look into the boiler of a steam-engine, you would see that the inside is quite clear, just as if it was full of air. Also in the clearest air there is always a large amount of steam; and mist and clouds are made up by the cooling and building up of liquid water in the shape of tiny drops. So you see these things behave in very much the same way as water and ice. Water and steam only exist together at a definite temperature, and when they are present together that must be the temperature.

P. How does it happen that it is exactly 100° ?

M. In every thermometer the 100° is marked just where the mercury rises to in boiling water.

P. How can they do that?

M. Don't you remember how we left the thermometer-maker? He had only been able to put one mark on his tube, and had written 0° there when the mercury was in melting ice. Now, he must have another distinct temperature to have another mark, in order that he may divide up his instrument. This second temperature is that of boiling water, and people came to the conclusion that the portion between the two marks was to be divided into a hundred parts. As the lowest mark is called 0° , the top one must be 100° .

P. Now I understand. But how can higher or lower temperatures be measured?

M. As many equal divisions are marked below the zero-point and above the 100-point as there is room for. According as the thermometer is required for high or low temperatures, more or less mercury is put in, so that there is enough space over on the required part (Fig. 8).

P. But our window-thermometer is not divided up to 100° . It stops at 50° . How could they make the right division in that case?

M. First a thermometer is made with great care from 0° to 100° and correctly divided. That is called a normal thermometer. Then the short thermometer is brought into the same medium as this—for instance, both are dipped into a rather large quantity of water. Since obviously both thermometers must now register the same temperature, we have merely to mark on the small one the number at which the mercury stands in the large one.

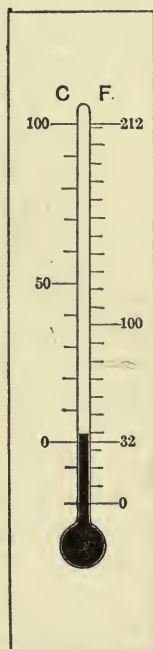


FIG. 8.

P. Is that how it's done? Now, I don't think I've anything more to ask. Yes, I have though; on the left of our window-thermometer is a C. and on the right an F., and it is divided differently on both sides.

M. F. means Fahrenheit. Fahrenheit was a German who made the first comparable thermometer; he lived in the eighteenth century. He wanted to divide his thermometer from the lowest temperature that there was; so he put it in a mixture of snow and sal ammoniac, and marked the point to which the mercury sank as 0° . The piece between this point and freezing-point of water he divided into 32 parts, and found that 180 of these parts were contained in the space between freezing-point and boiling-point. People used the division of Fahrenheit for this reason alone, because the freezing-point was 32° and the boiling-point $32^{\circ} + 180^{\circ}$, or 212° .

P. Why don't they still use Fahrenheit's plan?

M. Because the mixture of sal ammoniac and snow is very difficult to bring to a definite temperature, while the freezing- and boiling-points of water are much surer.

P. Does every one use these thermometers?

M. The English and Americans do. They use them only in ordinary life, however, mostly for open-air thermometers. In all scientific work they use the centigrade thermometer. Give me the equation between Celsius and Fahrenheit, and use the letter *f* for Fahrenheit, and *c* for Celsius.

P. $f:c = 180^{\circ}:100^{\circ}$, or $5f = 9c$.

M. That is not right.

P. Why not?

M. The freezing-point of Celsius is zero. If you say $c=0^{\circ}$, then your equation comes out to $f=0^{\circ}$. But the

freezing-point of Fahrenheit is not 0° , but 32° . What must you do so as to make $f=32^{\circ}$ when $c=0^{\circ}$?

P. I must put the 32 on the other side.

M. Well, let me hear the equation.

P. $5f=9c+32$.

M. Put the $c=0$ in here. Now what happens?

P. $5f=32$. No, that is not right; the f must stand alone on the left. How can I do that? Now I know: First, I must write $f=\frac{9}{5}c$ and then add 32 to the right; so $f=\frac{9}{5}c+32$. Now, I put $c=0^{\circ}$ and that comes right; $f=32^{\circ}$.

M. Yes, now the equation is right.

P. I have read about a thermometer called Réaumur that was quite different.

M. Yes. For rather more than a hundred years the thermometer of a Frenchman, Réaumur, has been used. In his, the space between freezing- and boiling-point was divided not into 100, but 80 parts. On the other hand, the Swede Celsius introduced the division of 100. In Germany the Réaumur thermometer came into use, while in France the centigrade one was used. Presently people grew accustomed to register all temperatures by the centigrade thermometer; in science no other is now used. What is the relation between the degrees of Réaumur and Celsius?

P. 100° C. are 80° R.

M. Simplify the proportion.

P. 10° C. are 8° R., or 5° C. are 4° R.

M. You can write this as an equation too. Take c for centigrade and r for Réaumur degrees—that makes $c:r::5:4$, so $c=\frac{5}{4}r$, or $r=\frac{4}{5}c$. The first equation you

use when you wish to change Réaumur into centigrade, and vice versa.

P. Has the mixture of ice and the other thing really—

M. Sal ammoniac?

P. And sal ammoniac the lowest temperature that there is?

M. Far from it! It is sometimes colder here in winter. Think how many degrees of Celsius there are to the zero of Fahrenheit.

P. I must put $f=0$; then $0=\frac{9}{5}c+32$; that makes $-17\frac{7}{9}$.

M. Yes, not quite 18° under 0° ; but in America it is often 20° to 25° below zero.

P. What is the greatest cold that there is?

M. Up to the present 259° below 0° has been attained.

P. What do you mean? Will they get further?

M. Not much. Probably -273° C. is the lowest temperature there is.

P. Why do you think that?

M. I can't explain to-day, but you will soon discover and believe it as well.

P. Oh, I wish I knew!

7. MEASURING.

M. What did you learn yesterday?

P. How thermometers are made.

M. Yes. As a thermometer is a sort of measuring instrument we will speak a little about measurement. What can be measured?

P. All sorts of things: Lengths, weights, surfaces. I think almost everything can be measured.

M. Not all, but a great many things. What is used for measuring?

P. A measure.

M. What is that?

P. There are different sorts; it depends on what you want to measure.

M. Give me an example.

P. Well, the length of the table can be measured in feet and inches.

M. Although feet and inches are used in England and America, all scientific people measure in what is called the metric system.

P. What is that?

M. We are going to learn it. Here is a centimetre rule. Measure the length of the table.

P. The scale is 50 centimetres long; I see that on the last figure. I lay the measure so that its end is against the end of the table, and notice to where it reaches. Then I put the measure at that mark, and again make a scratch where it ends. My measure comes beyond the table, now that I have put it at the second mark, and I look at which number the table ends. It is at 22. So the table is $50 + 50 + 22 = 122$ cm.

M. Quite right. You went on adding centimetres together till you had got the same amount as the length of the table. The measure only helped you to count the centimetres.

P. Yes, so it did.

M. And how do you set about measuring weights?

P. I put the thing in one pan of a balance, and add weights to the other, till they are both the same weight.

M. And how can you notice, or tell the weight?

P. The number of ounces each one weighs is marked on the weight; I add the figures all up afterwards.

M. Let us use grams. You see it is the same as before; you add grams together till their weight is the same as that of the object. The weights only help you to count the grams.

P. So they do. I never noticed that both were so like.

M. You will soon see that all real measuring is based upon the same principle. But now for another question: Why didn't you measure the length with grams and the weight with centimetres?

P. It wouldn't work.

M. Why not?

P. However many centimetres I put together they would never make a weight.

M. Quite right. Put this in a simple form.

P. Length can be only measured by length, and weight by weight.

M. It could be said still more simply. Every quantity can be measured by a like quantity.

P. Yes, I understand that.

M. You measured length in centimetres. Are centimetres the only measure of length?

P. No, there are millimetres, kilometres, inches, miles, fathoms, and a great many others.

M. How far do these differ?

P. A centimetre has a different length from an inch, and so on.

M. Yes; these definite lengths, such as a centimetre, inch, and mile, are called units of length. In every statement of measurement we get the kind of unit which has been used, and the number of units which are contained in the thing measured.

P. Then why are there so many sorts of units for the same sort of quantity; for example, length?

M. That is because the choice of the units is arbitrary. At first different groups of people who required a unit of length chose one without troubling themselves about what other people were using. Finally these differences grew so unbearable that in France, at the end of the eighteenth century, the State determined to abolish the old measurement and to use a new one in its place. It was determined to protect the standard against accidental destruction, and so it was

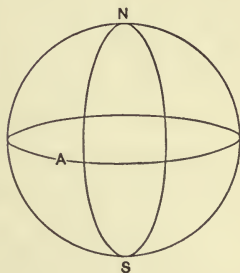


FIG. 9.

decided to use the world itself as a measure. The length of a quadrant of the meridian, that is, the length from *A* to *N* (Fig. 9), was divided into ten million parts, and these parts were called metres, and were to serve as a common unit of length. A centimetre is a hundredth part of this length, so that it is a thousand-millionth of the earth's quadrant.

P. But how can the earth's quadrant be divided, when no one has been to the north pole?

M. Only a part of it is measured, the relation of which to the whole is determined by the angle which lines at right angles to two tangents form with each other. But it turned out that this measurement was far less accurate than the comparison of two metre scales. Accordingly the metre was taken to be the length of a standard kept in Paris, made of the most indestructible material which could be found—an alloy of the noble metals platinum and iridium.

P. But supposing this scale was lost or got destroyed?

M. Care is taken about that. Twenty similar scales have been made, all carefully compared with each other, and there is one at Berlin, London, New York, St. Petersburg, Rome, and many other places, so that any one of them might be lost without the loss of the standard. Then, again, many other scales made of different materials have been compared with them, so that the permanence of the unit is about as certain as that of the human race.

P. But the metre is quite an arbitrary measure. Why hasn't one been chosen which is free from man's control?

M. Because there is practically none.

P. But with angles it is different. I have learned in my geometry class that a right angle is a natural measure which cannot be altered. Why can't that be done with lengths?

M. Tell me any natural measure of length.

P. ——. No, I am afraid I can't. But why is there a difference?

M. It depends on the fact that an angle cannot be made infinitely great. If you rotate a straight line round a point in another straight line, the angle between both increases at first, but it can't become larger than four right angles, for that angle is equal to the angle 0, and afterwards the same angles come as before. The largest possible angle has consequently a finite value, and that value is the natural unit. But with length it is different, for you cannot think any length so great that it could not be made greater.

P. So nothing which can be made infinitely great can have a natural unit?

M. Quite right. You will soon become convinced that for all such magnitude arbitrary units must be

chosen. The best proof is that no one has been able to find a natural one. Now we will go back to the metre. It is not convenient to measure all magnitudes of the same kind by means of the same unit. You can measure the length of the table in centimetres; but if you measure the height of a hill or the length of a river in centimetres, your numbers will be far too large, and for such great lengths larger units are employed.

P. Yes, I know; metres and kilometres.

M. Right. People have used such different units for a long time, but they did not stand to one another in a sufficiently simple relationship. At the same time as the metre was introduced, it was decided only to admit such measures of the same kind, as stand to each other in the proportion 1:10:100:1000, and so on; that is, in powers of 10.

P. Why was that done?

M. Because in reducing from one measure to another there is hardly any work to be done; you need merely add zeros, or alter the position of the decimal point. Thus you have:

1 kilometre (km. for short) = 1000 metres (m. for short).

1 m. = 10 decimetres (dcm.) = 100 centimetres (cm.) = 1000 millimetres (mm.).

P. What is the meaning of kilo?

M. Kilo is the Greek word for a thousand. It was agreed at the same time that the multiple of each unit should be expressed by Greek prefixes (deca-, hecto-, and kilo-); while the fractions are expressed with Latin prefixes (deci-, centi-, milli-).

P. Now I understand the meaning of the words kilogram and milligram.

M. You see the unit of mass is called the gram. It is

derived from the centimetre; it is the mass of a cube of water at 4° C. The multiples deca-, hecto-, and kilogram are derived from it, but only the last (kgrm.) is in use. A kilogram is equal to two pounds. The deci- and centigram are also not often used; but the milligram (mgrm.) = 0.001 gram is much used in scientific work.

P. You said that the gram is the unit of mass. I thought it was the unit of weight, for people weigh with grams and kilograms.

M. Mass and weight are related to each other. Mass is the property of bodies which keeps them in motion when they are once moving; and mass is measured by the work which must be expended in order to produce equal velocities. Now weight or the force with which bodies are drawn to the earth are at any given place exactly proportional to the mass, so that when two weights are equal the masses are also equal. And for that reason masses can be measured by help of weights.

P. Why do we require to know masses? Surely we buy bread and iron and gold by weight.

M. Yes; by weight, but not on account of weight. In science weight is derived from mass, and not mass from weight, because the mass of any body is unchangeable although its weight may be altered.

P. But if I keep a thing carefully shut up, so that nothing is lost, surely its weight remains unchanged?

M. I don't mean it in that sense. Of course, if you take anything away from a body, its mass will be decreased in the same proportion as its weight. No; a body has a smaller weight on a high mountain than in a valley. And weight is less at the equator than at the pole.

P. I remember learning that in my Geography lesson;

it had to do with the attraction of the earth. Because the earth is flattened at the poles, a body there is nearer the centre of the earth than at the equator.

M. Quite right; but you must add that the attraction decreases with the distance from the centre of the earth; moreover, near the equator the centrifugal force increases, so that a body near the equator is more swung off from the earth than if it is near one of the poles, and it consequently weighs less.

P. If I weigh a kilogram of sand here, and carry it up a high mountain and weigh it again, would it really weigh less?

M. Not if you were to weigh it on an ordinary balance with arms; it would counterpoise exactly as much weight there as here.

P. But you said—

M. Don't you see that your weights become lighter in the same proportion as your sand?

P. How can that be? Oh, I see; I hadn't thought of it. But I can't understand how it can be proved that the weight has become less.

M. By determining the weight, not by help of counterpoises, but by another method. A spring balance, in which weight is measured by stretching a spring, would show that your sand weighed less on the top of a hill than in a valley. The most exact measurement is made with a pendulum, for it swings more quickly the greater the attraction.

P. Why?

M. You will learn it in your Physics lesson. We must go back to our old subject. I told you that things are bought by weight, not because of weight. Why do people buy bread?

P. To eat it.

M. Do you eat it in order to grow heavier?

P. Ha! ha! ha! No, because I like it and because it makes me strong.

M. The last is the important reason. And coals are bought, not because they are heavy, but because they make you warm.

P. But I can't understand the use of weight.

M. Which would you rather have, a small piece of cake or a large one?

P. Of course, a large one.

M. Why?

P. Because there is more of it. A little one wouldn't satisfy my hunger.

M. And which weighs more?

P. The larger one, of course.

M. Now you see the use of weight. The properties and uses which make us buy things increase or decrease with the mass or the weight. The power which bread has of keeping you alive increases proportionally to its weight, and the greater the weight of the coal you buy the more heat you can get from it, and just as with these marketable properties, so a great many scientific properties are dependent on the mass and on the weight. The balance is therefore a very important piece of chemical apparatus, not so much because we want to know the weight of things, for often we do not care to know it, but because of the other properties which are connected with weight.

P. So weight is like the paper of a book, which is worth very little in itself, but becomes valuable for what is printed on it.

M. That is a good comparison even though it doesn't

quite fit. Let us take a better example. As you know, liquids are bought and sold both by measure and weight. Wine and beer are sold only by measure, that is, by the space which they occupy; paraffin-oil is sold both by weight and by measure; sulphuric acid is sold only by weight.

P. Why?

M. Convenience and custom are the reasons. Measuring is much quicker than weighing, and a measure is much more easily made than a balance; and so this plan is preferred. But sulphuric acid is a somewhat dangerous liquid, and people don't like to pour it; therefore they prefer to weigh it. But for the purpose of determining quantity by measurement, for any one substance volume and weight bear a constant proportion to each other. Hence the actions and uses of liquids are proportional to their volumes, just as they are to their weights. The purchaser of paraffin-oil is not interested in the volume it occupies or in its weight; he buys it because of the amount of light or heat which he can get from it. But these amounts are proportional to the volume, and so the volume becomes a measure for the amount of light which the paraffin-oil will produce. Now tell me what you know about measures of volume.

P. The unit is called a litre.

M. That is only half right. The real unit of volume is derived from the unit of length, and is a cube, the side of which is one metre long—a cubic metre. But this measure is far too large for most purposes, and therefore one has been chosen nearer in volume to the old pints and gallons. It is a cube, the side of which is $\frac{1}{10}$ of a metre; its capacity therefore is $\frac{1}{1000}$ of a cubic metre. It is called a cubic decimetre, or a litre (l.).

P. You have surely made a mistake in saying that a cubic decimetre is a thousandth of a cubic metre. A decimetre is only a tenth of a metre.

M. Think a minute!

P. What a stupid I was! The volume of a body is proportional to the cube of its side, and $10 \times 10 \times 10 = 1000$.

M. Yes, that is right. In science we use as a measure one-thousandth of a litre. How large is that cube?

P. I won't make another mistake. The side is ten times less. $\frac{1}{10}$ dcm. is $\frac{1}{100}$ m. It is a centimetre.

M. The measure of volume is called cubic centimetre (ccm.). Now write me down a table of measures of volumes.

P. 1 cbm. = 1000 l., and 1 l. = 1000 ccm.

M. Quite right. Now we have had enough for to-day, although there is a great deal more to say about measurement.

8. DENSITY.

M. Yesterday you learned how to measure and to weigh; to-day we will talk a little more about measurement. Which is the lighter, a pound of lead or a pound of feathers?

P. You can't catch me with that old joke. Of course they are the same weight.

M. But which is the lighter, lead or feathers?

P. Hm! Well, feathers are really lighter.

M. That is a contradiction. It depends upon the fact that the words light and heavy are used with a double meaning. When you say lead is heavier than feathers, you mean that a handful of lead has a greater weight

than a handful of feathers; if equal volumes of feathers and of lead are compared, the lead weighs more. If we say wood is lighter than iron, we attach the same meaning to the word lighter, although you could easily choose a given piece of wood heavier than a given piece of iron.

P. I understand that.

M. But in science it doesn't do to use such indefinite expressions. The property which is greater with iron and lead than with wood and feathers is called *density*, and we say iron is denser than wood and lead denser than feathers. How is density determined?

P. By weight and by volume.

M. Yes. And as the density is greater the greater the weight in a given volume, and smaller, the greater the volume of a given weight, the density is made proportional to the weight and inversely proportional to the volume; so that if w is the weight and v the volume, the density d is expressed by the formula

$$d = \frac{w}{v}.$$

P. What is the use of this formula?

M. To measure the density. Let us take an example: What is the density of water?

P. It depends on what weight and what volume you take.

M. No, it doesn't depend upon that. We choose once for all the *gram* as unit of weight and the *cubic centimetre* as unit of volume. Now, if we take an arbitrary quantity of water, say a litre, what is its weight?

P. One litre of water weighs 1000 grams.

M. And what is its volume in cubic centimetres?

P. 1000 c.c. make a litre.

M. So we have $w = 1000$ and $v = 1000$; how large is d ?

P. $d = 1000/1000 = 1$; the density is 1.

M. Now make the same calculation for 20 c.c. of water.

P. $d = 20/20 = 1$. It is 1 again. Oh, I see; because the volume and the weight always become larger and smaller to the same degree, the fraction must always have the same value whatever quantity of water is taken.

M. Now you understand it. Here I have a little lead cube; what is its density?

P. I must first find its weight. Let me weigh it myself. It weighs 38.84 grams. And now I must find its volume. But how can I do that?

M. As it is a cube you have only to determine the length of one side. Here is a rule.

P. The side is 15 mm. long, and so the volume is $15^3 = 3375$.

M. Equals 3375 what?

P. 3375 c.mm. Oh, I should give the volume in cubic centimetres. I'll be right this time. The volume is 3.375 c.c.

M. Quite right. Now calculate the density.

P. $38.84/3.375 = 11.51$.

M. So the cube has the density 11.51. I can go further and say that lead has the density 11.51, for if I had taken any other cube of lead, or indeed any other piece of lead, I should have found the same number. Tell me why.

P. I can see that you would have got about the same number, but I am not sure that you would have got exactly the same number.

M. You have forgotten what I told you before (page 2)

about properties. Density is a property; for all samples of the same substance it will have the same value. Now ordinary lead is really a very pure substance, and contains hardly anything mixed with it, and so the properties of different samples have the same value.

P. But all bodies expand with heat; so that the volume of the lead cube will be larger when it is warm than when it is cold.

M. Quite right. Is weight changed by heat?

P. Not so far as I know.

M. Weight is quite independent of temperature. So it follows that the density of lead becomes smaller as the temperature rises, because while the numerator remains the same, the denominator increases:

P. Then density isn't quite a definite property.

M. Yes, it is, for at a definite temperature it has a definite value. The same holds for every other substance. Water, too, changes its volume with temperature; and therefore 4° has been chosen as the temperature at which the weight of 1 c.c. is called 1 gram.

P. Why was that temperature chosen?

M. Because water has its greatest density or its smallest volume at 4° . What are you thinking about?

P. I am thinking how it would be possible to determine the density if the thing wasn't a cube.

M. That is a very sensible question, for very few substances can be made into that shape. Look here, I'll show you how it can be done. Here is a glass tube which is divided into tenths of cubic centimetres by little lines. I pour water into it and read where the level stands; I find 5.33 c.c.

P. You have read off hundredths, and there are only tenths marked upon the tube.

M. Every one who makes measurements must learn to do that. As a rule, the level of the water does not lie neatly on a line, but between two. I divide the distance between two lines into tenths with my eye, and so I get my hundredths.

P. I couldn't do that.

M. It isn't difficult to learn, and you must try it afterwards. But now we will go on. I have here a glass with shot. They are made of lead; weigh it.

P. It weighs 43.58 grams.

M. Now I shake some of the shot into the tube. Weigh the glass again.

P. It weighs 28.42 grams.

M. What is the weight of the shot that I have shaken into the tube?

P. $43.58 - 28.42 = 15.16$ grams.

M. And now I read the level of the water in the tube. It stands at 6.66. That is 1.33 c.c. more. What conclusion can I draw?

P. Oh, now I see. The volume of the water has risen so as to tell the volume of the shot. The volume of 15.16 grams is 1.33 c.c., and so its density is 11.40. It is *almost* exactly the same number that we calculated before. But it is not exactly right.

M. Because you didn't measure with sufficient accuracy. You gave the side of the cube as 15 mm.; measure again.

P. Yes, it is a little smaller.

M. And measure the other sides of the cube.

P. They are not quite equal.

M. You see, then, that your former measurement contained errors, and therefore the result cannot be quite accurate. To measure exactly is a very difficult thing;

and therefore we must rest contented at present with what we have found; the right number is 11.4. I will let you use the balance and the measuring-glass, and you can determine for yourself the density of various substances. But take care that you always remove the bubbles of air, or you will measure them along with the volume of the body, which will appear too great, and you will get too small densities.

P. Yes, I will draw up a table. What shall I measure?

M. You had better find the densities of your minerals. But now to another question: Have liquids also definite densities?

P. I think so. Yes, water has the density 1.

M. Right. Now think; how can you determine the density of a liquid?

P. By determining its weight and its volume. Wait, I know. I shall pour it into the measuring-glass and read out its volume.

M. And how will you find its weight?

P. Exactly as you did with the shot. I shall first weigh the flask which contains the liquid, then pour it into the measuring-glass, and then I shall weigh the flask again.

M. It can be done in that way, but it is possible to do it in a much simpler manner. Weigh the measuring-glass once for all, then pour in liquid and weigh again, and you need only subtract the weight of the measuring-glass.

P. That gives me one weighing less.

M. You can lessen your work still further by not measuring out an arbitrary quantity of liquid, but a definite volume. This is not easy with solid bodies,

but is quite easy with liquids, because they fill a given volume completely. For example, if you pour exactly 1 c.c. into your measuring-glass, and determine its weight, what will your equation be?

P. Then $d = g/1$. That is $d = g$; the weight is the same as the density.

M. Do you see you don't require to divide. It is often said that the density is the weight of unit volume. This expression is not wrong, but doesn't cover enough, and so I didn't tell you it before.

P. I have just tried to pour 1 c.c. of water into the measuring-glass, but it is very difficult to get exactly the right amount. I have found either too much or too little.

M. Pour in a little too much, and then remove the excess with a small strip of blotting-paper. It sucks up such small quantities that it is quite easy to obtain the right volume.

P. Yes, that works.

M. It is still easier with this apparatus (Fig. 10), which is called a pipette (this is a French word and means little pipe). I suck the upper end while I hold the lower in the liquid, until the level rises above a mark on the stem; then I close the end quickly with my forefinger, and while the point touches the side of the vessel, I can easily let so much liquid run out that it stands exactly at the mark.

P. But I must put the liquid in another vessel to weigh it.

M. No. You can lay the pipette itself upon the scale. If you have determined its weight, when empty once for all,

you need only subtract that from the total weight and you have the weight of a cubic centimetre, or the density. It is still simpler to make a counterpoise of wire of the same weight as the pipette. Such a counterpoise is called a *tare*. Then the remainder of the weights on the pan will give you the density.

P. I'll certainly do that.

M. In that manner you can determine the densities of various liquids, such as spirits and salt water. You will find the first lighter, the second heavier, than water.

P. Then I can make a table of densities of liquids as well.

M. Now you know how to determine densities of solids and liquids, what about gases?

P. Can't their densities be determined in the same way by measuring their weight and their volume?

M. Of course they can, but it is not so easy. In the first place the weight of a large volume of air is very small; 1 litre of air weighs only a little more than 1 gram, as you have seen already. Then the volume of gases is very easily changed if the temperature or the pressure alters. And so very different densities are got for the same gas if it is measured at different temperatures or pressures.

P. But that happens too with solids and liquids.

M. The changes are much smaller with them, so that they need only be taken into account if great accuracy is required.

P. Then how is the density of a gas determined?

M. That is a rather difficult thing, which I shall explain to you later. To-day I will merely say that people have determined upon a standard temperature and a standard

pressure at which to measure the volumes of gases, and so uniform results are obtained.

P. I should never have thought that measuring was such a difficult matter.

9. FORMS.

M. I am not going over to-day what you learned yesterday, because it was really just a repetition of what you had learned before. We will go back to what we spoke about in the lesson before last. You learned two very different properties of water. What law is at the bottom of the melting of ice and boiling of water?

P. That both happen at a definite temperature.

M. Yes, but not only water; every substance has these properties.

P. Really all?

M. All substances that are really pure substances. Mixtures and solutions have changeable melting- and boiling-points.

P. How changeable?

M. If a solution is brought to boiling point, we notice, as the boiling proceeds, that the temperature doesn't remain unchanged, as with pure substances, but gradually rises, in proportion to the amount of steam that goes away. In the same way, when a mixture fuses or melts, it begins to liquefy at a definite temperature; this does not remain stationary, however, but rises higher as more heat is added and more of the mixture becomes liquid.

P. May I see that?

M. Later. At present we will stick to pure substances. You have seen that liquid water can be changed

into solid ice and into gaseous steam. Do you know what these two conditions are called?

P. Yes; states of aggregation.

M. Quite right; that is the usual name. What does it mean?

P. Aggregate means assembled, but I don't know what that has to do with liquid or steam.

M. The name is given because it is taken for granted that all bodies are made up of tiny particles which are able to lie on each other, or arrange themselves in various ways. They are called atoms. According as these atoms are near or far from each other, they make solid, liquid, or gaseous bodies.

P. Can you see these atoms with a glass?

M. No, not even with the strongest microscope. People take for granted, because of that, that they are smaller than the smallest thing that can be seen through a microscope.

P. But are they really there?

M. It is true I cannot guarantee them. There is no proof of their existence.

P. Then how can you say that it depends upon them whether a body is solid or liquid?

M. Real things behave in many respects as if they were collections of atoms, if atoms exist. If it be assumed that bodies consist of atoms, it may be deduced that they must behave as they really do.

P. That is very awkward. Why do people not simply say: They behave this way or that way, and be done with it?

M. Because, starting with the assumption of atoms, there can be deduced several conclusions which agree with fact. Such an assumption is called a hypothesis.

P. But I can't see what is gained if there is no proof that the hypothesis is true.

M. The hypothesis serves to make the real relationship more easily noticeable. If you have to keep in mind three names, Alfred, Arthur, and Anthony, it will be easier for you to remember them if you notice that they all begin with A. Moreover, a hypothesis serves as a stimulus to research. People imagine how a number of atoms would behave under given circumstances, and find out whether the actual bodies behave in that way.

P. Do they always agree?

M. No, I am sorry to say, not always.

P. But after such a conclusion has been drawn, people ought to see whether it is right or not.

M. Certainly; but this gives an opportunity of putting definite questions to nature and of making suitable experiments or observations. And so our knowledge increases, and that is always an advantage.

P. But if they don't agree?

M. Then there is nothing for it but to wait and hope that the contradiction may be explained.

P. But that is a very uncertain way of doing things.

M. So it is; yet the use of hypotheses for learning and investigation is so great that people will always make use of them.

P. Couldn't they do without them?

M. Of course they could; but people are so much in the habit of using hypotheses, like the atomic hypothesis, that they find great inconvenience when they try to realize things without their help. And therefore they will not give them up.

P. Then please explain to me how solid, liquid, and gaseous bodies are built up of atoms.

M. Ah, you put me in a difficult position if you wish me to show you the use of the atomic hypothesis, for up to the present it has not been entirely satisfactory. However, we needn't delay over that at present; I only mentioned the subject in order to explain the derivation of the name "state of aggregation." In talking over these things with you I prefer to consider these relations without its help; and for that reason I will not use the term, but rather speak of forms.

P. What does the name mean?

M. It points to the chief differences of these states. How does a solid body behave in relation to its form?

P. I don't know anything particular to say about that; it can be broken, cut, or bent.

M. But if it is left alone?

P. Then it keeps its form.

M. Right. Have you ever thought how important that is?

P. I don't see anything very important about it. Sometimes it is a great nuisance; for example, if I want to break sugar.

M. Think for a minute. If the stones and rafters of this house were to change their shape, it might fall to pieces at any moment; none of our tools would be usable; you couldn't cut with a knife if the blade didn't keep its shape; your morning milk wouldn't stay in its can if the shape of the can kept changing continually.

P. Yes, now I see, but I can't think it out to the end. The whole world would go to bits.

M. Now I see you are beginning to grasp it. Have all bodies the property of keeping their shape? For instance, how does water behave in this respect?

P. Water does not keep its shape; you may pour it into any sort of vessel you like.

M. Is water the only thing that has this property?

P. No, all liquid bodies are like it. Yes, now I see the great difference. But how is it that solid bodies keep their shape?

M. That is a senseless question. How do you know when a body is solid?

P. I catch hold of it.

M. And you are convinced that it keeps its shape. The word solid is merely the name for the common properties of many bodies of keeping their shape.

P. But that must have a cause.

M. I don't understand you.

P. Why is this silver coin not liquid?

M. Well, when you heat it, it melts and becomes liquid. Here is a piece of thin silver gauze; if I hold it in the flame it will liquefy, and a drop will form on the end. See, the drop has fallen.

P. So it has.

M. The question whether a body is solid or liquid depends solely upon its temperature. Below its melting-point it is a solid, and above its melting-point it is a liquid.

P. Is that the case with all bodies?

M. Yes.

P. Then, by cooling, any liquid can be made solid, and all solids become liquid when heated?

M. Generally. If substances do not decompose they behave in that manner. Only there are liquids the freezing-point of which is very low, and solids which melt at a very high temperature. There are melting- and freezing-points in all regions of temperature.

P. Why does a solid freeze at a definite temperature?

M. That is another senseless question. You can only ask: What is the freezing-point connected with? It is just as if you were to ask: Why are there camels? Whereas one can only ask: What properties have these animals, and how do these properties compare with those of other animals? In the same kind of way, melting-points are phenomena of nature, and have definite relations to other phenomena.

P. What sort of relations?

M. If I were to answer that question you wouldn't understand, for you would first have to know those other properties.

P. Yes, that is true. I see you would require to know the other properties before you could compare relations between them.

M. Yes. So we must begin our work by collecting facts, by writing them down, and then by comparing them with each other in order to find out in what they agree. That is how laws of nature are discovered.

P. I never thought of it in that way. I supposed that some very clever man must have discovered them all by himself.

M. Nobody does anything all by himself, as you call it. But think a minute. One law of nature tells us how certain things will behave under definite conditions. The thing must be known under those conditions before such statements can be made.

P. Yes, that is so; but then every one must be able to discover laws of nature.

M. And so any one can, if he finds things in conditions which have not yet been sufficiently investigated. But that is rather difficult, because the common and ordinary conditions of things are already discovered; and it is very

hard to acquire enough exact knowledge to find undiscovered spheres to examine. For instance, it would be quite easy to discover the north pole if you could only get to it. The difficulty is not to see the north pole, but to get a place from which it can be seen.

P. Then I will really learn thoroughly, and perhaps later I may discover something.

M. Yes, do so. You know the end in view, anyhow. But now we will return to our subject. Do you understand now the meaning of the name forms?

P. Yes, solids have forms, but liquids haven't.

M. That is partly right; but what about gases?

P. They haven't any form, either.

M. How do they differ from liquids?

P. They are far lighter and thinner.

M. Yes, that is right, but you haven't come to the main point. If I pour some liquid into a vessel, it falls to the bottom, and fills the vessel according to the amount. But if I put gas in an empty vessel, what happens then?

P. I don't know; a gas can't be seen.

M. It fills the whole vessel, however much or little there is.

P. That is extraordinary. How do you know that?

M. Only a definite amount of any sort of liquid can be poured into a given vessel, that is, as much as there is room for. If less is put in—

P. A part of the vessel remains empty.

M. Right. If you attempt to put more in, it doesn't work, for a liquid doesn't allow itself to be pressed together, or, to be exact, only slightly. A great quantity of gas can be put into a given space, and it is always possible to put in still more.

P. Does that go on forever?

M. No; more and more pressure is needed for it. We shall soon go into these things more particularly. At present the difference between liquid and gaseous bodies is important to us. It is true that liquids have no definite form, but they have a definite space or volume, which is unchangeable whatever form they may be made to take. So a litre of petroleum is always a litre, whether it is in a can or a jug, or anything else it may be kept in.

P. And gases?

M. Gases have neither a definite form nor a definite volume, but spread themselves out through all the available space until they entirely fill it.

P. Then the name "form" isn't suitable for gases?

M. Not at all. Liquids take the form of whatever contains them, but only so far as they fill it. Gases take the form of whatever contains them, because they always fill it completely.

P. Then "form" is the way in which bodies take their form!

M. You may describe the word in that way.

10. COMBUSTION.

M. Now you know something more about all the three states, and can have a more complete idea that nearly all substances are known in these three forms.

P. Why not all?

M. With some the melting- or boiling-point is so high, or the freezing-point so low, that it is not possible to reach them.

P. Oh, I wanted to ask you about that a long time ago: are these changes of one form into another chemical or physical reactions?

M. You know that such a classification is more or less arbitrary. If we define a chemical process as one in which most of the properties of the substances concerned alter, then we must consistently define change of state as involving a chemical process.

P. But we spoke about melting and boiling in my Physics lesson, so they belong to physics.

M. Ice can be changed as easily into water as water into ice. But in chemical changes, only one change, generally, is easily made; the other causes great difficulty. Formerly, because of this difference, people did not consider change of form as a chemical change.

P. You said "formerly"; is it different now?

M. Now people have learnt that many changes which are generally called chemical can be reversed, and are subject to the same laws as physical changes.—But now we will turn to things which have always been looked upon as chemical. Have you ever looked at a candle burning? Yes? Then describe to me what you saw.

P. When you light a candle it burns down till it is all gone, and during this it has a hot, bright flame.

M. Right. What is necessary for burning?

P. Well, the candle.

M. Nothing else?

P. Not that I know of.

M. If you put the burning candle in water—

P. It goes out.

M. Why? What is different from before?

P. It has no more air,

M. Right. For burning, then, it is necessary to have the candle and air. I will show you now that a candle can burn under water if it is only put under together with air. I let a little board float about on the water in this large glass, place a bit of burning candle on it, turn a glass upside down over it, and now I can dip the whole thing under; the candle is burning (Fig. 11).

P. Oh, that is pretty! Please hold it a little longer like that. Ah! the flame has gone out. Some water must have got on the wick.

M. We will make the experiment again, and hold the glass quite still.

P. The flame went out again, after it had burnt a little.

M. Now we will leave out the water altogether. I put the little candle on a smooth plate of glass and place a glass beaker firmly over it.

P. The flame is going out again.

M. What must you conclude from this experiment?

P. That the candle can't burn for long in a glass beaker.

M. That would not be right. I put my beaker upright, and put the candle in. You see it burns, perhaps a little unsteadily, but it doesn't go out.

P. Cover it with something. May I? Do you see now the flame is out again.

M. How can you express that knowledge?

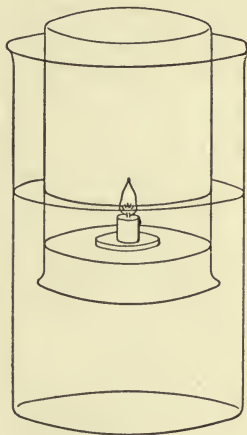


FIG. 11.

P. A candle can only burn for a short time in a covered glass.

M. Must it only be a covered glass?

P. I don't think so.

M. It needn't be any one thing. An extinguisher puts a candle out, as you know, and it is made of metal. But why does a candle burn in a lantern?

P. Because it has air-holes.

M. What have they to do with it?

P. Fresh air always comes in at them, and the used-up air gets out at the top air-hole.

M. Now just try to put together all that we have spoken about.

P. The candle requires air to burn. In a closed space a candle can burn only a short time. If the air in this space is changed, the candle can burn longer.

M. Good. But this room is a closed space, and yet the candle can burn here as long as it will last.

P. Yes, because the room is so big.

M. There you have discovered something. So you think that the larger a closed space is the longer a candle will burn in it?

P. Yes.

M. It is so. But there are many important conclusions to be drawn from it. Can you give me any reason why that is the case?

P. No.

M. We will look for resemblances. A short candle will only burn a short time, a long candle, a long time. Why?

P. Because in burning the candle gets used up. Should the air get used up by burning?

M. Look for a moment. I have here a candle

attached to a wire, and lower it, burning, into a bottle (Fig. 12). When it has gone out I take it carefully out and light it. If I put it at once in the bottle again—

P. It goes out immediately.

M. It follows from that that the air in the bottle is used up.

P. How? There is some there still.

M. That isn't air. Air has the property that a candle can burn in it. What is in the bottle has not this property.

P. But it looks just like air.

M. Quite so; what is in there is a colourless gas like air, but not what we call air. A chemical change has taken place with the air, and it has other properties.

P. Other properties? Yes, the candle doesn't burn any longer. But beyond that I don't see any other properties.

M. That is because nearly all gases look very much like each other. The difference of their properties is only brought to light after careful searching. I have here a large flask with ordinary mortar shaken up with water and left for a while. Most of the mortar has sunk to the bottom, but a little has dissolved in the water. It seems also as if the water had kept its properties; it doesn't look any different. But still it has changed. Taste it!

P. How unpleasant! like soap! It isn't poisonous?

M. No. I pour some of the lime-water into a bottle

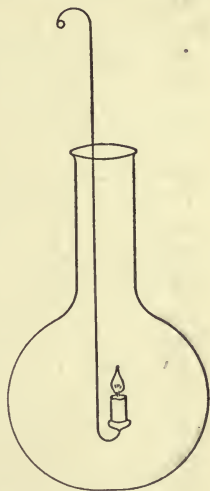


FIG. 12.

which has ordinary air in it, and shake it. What do you see?

P. Nothing much.

M. The lime-water remains unchanged. Now I do the same with the bottle where the candle burnt.

P. The water is becoming quite milky.

M. So you see that the gaseous contents of the bottle in which the candle burnt has a property that ordinary air doesn't possess. The air then has gone through a chemical change.

P. So you can see by means of lime-water what you can't see with your eyes?

M. Yes. If we could see the new things in the air without help, we wouldn't need to make use of lime-water. A substance, which in such a way makes known something present, is called a reagent, and the event which is called forth by it, a reaction.

P. A reaction means that one thing acts on another?

M. Yes; the changed air and lime-water work upon each other, and so the white substance is formed which makes it cloudy. But now we will go still deeper into the subject. What happens to the candle by burning?

P. It vanishes.

M. Do you mean it goes quite away?

P. Yes. Nothing remains over from it.

M. But if your book or your apple goes away, then you ask where they can be. And in the same way with everything else.

P. Yes, they can't vanish.

M. But the candle?

P. H'm! But where can it be? It really vanished before my eyes.

M. Yes, it became invisible. Can't it have changed into something invisible?

P. There isn't anything invisible.

M. Oh! isn't there?

P. No, there aren't any spirits or ghosts.

M. It seems that even they are sometimes visible. But can you see air?

P. — No. But air is changed by burning. I can't understand that.

M. It is quite simple. The candle and air transform each other mutually by burning, and a gaseous substance is the result, which, owing to this state, cannot be seen.

P. Gaseous substances that aren't air?

M. So that is your difficulty? You know that many liquids look like water that aren't water. In the same way there are many gases that look like air, but are something quite different. On that account in the earlier developments of chemistry there was great difficulty, till characteristics like that with lime-water taught people to distinguish between the different gases. But now we will try another experiment. I light a candle again, and hold a large empty glass over it (Fig. 13). What do you see?

P. The glass is becoming cloudy, as if it had been breathed on.

M. What is the cloudiness that appears on a glass when breathed upon?

P. I know that; it is made by drops of water which come from warm breath, and are laid on the cold surface.

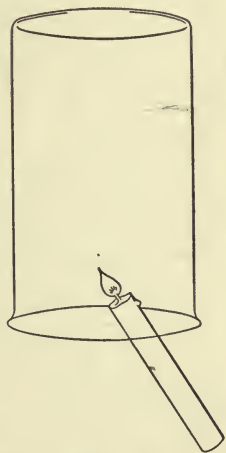


FIG. 13.

M. Right. What appears in the glass consists also of drops of water.

P. How do they get there?

M. The candle in burning changes itself partly into water.

P. That is extraordinary! I never thought of that. But water won't make the lime-water cloudy?

M. No, water never does that. Two new substances are formed when a candle burns. One is water and the other is that which makes lime-water cloudy.

P. What is it called?

M. Carbonic acid gas.

P. That is a funny name. What does it mean?

M. You can find that out later on.

P. The whole thing is becoming more and more muddling!

M. You are right. We will examine simpler cases first; if you understand them, you will understand the others. We are going to burn iron.

P. Can you?

M. Quite easily. You know what iron filings are?

P. Yes, they are little specks of iron which have fallen down in filing.

M. I sprinkle some iron filings in the flame.

P. How pretty! Just like little stars!

M. That is burning iron.

P. Why didn't the iron gauze burn when I held it in the flame?

M. It wasn't hot enough, for the heat is conducted off by the gauze. But the little iron specks, on the other hand, are quickly heated, and lose none of their heat by being conducted off.

P. Then large pieces of iron ought to burn, if they are made hot enough.

M. And so they do. Later on we will burn iron gauze itself. Iron burns also on melting, if it is glowing. The burnt iron breaks off with hammering.

P. But you don't see any flame.

M. There is such a thing as burning without flame. The little stars from the iron filings were not flames. We will make an experiment like that now. This black powder is also iron, only in far smaller pieces than ordinary iron filings. I put a small wire tripod on the balance, lay a narrow piece of wire gauze on it, and shake out several grams of iron powder on it (Fig. 14). The whole thing is now made to balance. Then I hold

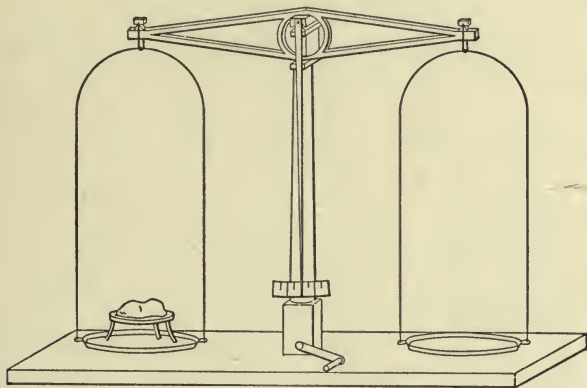


FIG. 14.

a flame to the edge of the little heap. Now it is beginning to burn.

P. I only see it glowing.

M. That is how powdered iron burns. Charcoal can only glow when it burns.

P. That is true. But why have you put it all on a balance?

M. You will soon see. What do you think? will iron become lighter or heavier by burning?

P. I should think lighter. The scale with the iron will rise.

M. Notice carefully.

P. It is sinking! Perhaps it was only a draught. No, it is getting heavier. That is very odd.

M. Why?

P. One time a thing becomes lighter by burning, another time heavier.

M. In the case of the candle the thing that was made by burning went away, with iron it remains. If it stays, it increases the weight.

P. With the candle as well? I'd like to see that.

M. To do that, you have only got to keep hold of what is made by the candle burning—water and carbonic acid gas.

P. That must be rather difficult.

M. Not very. There is a substance called caustic soda which has the property of binding together every trace of water and carbonic acid gas with which it comes in contact. I put some loose pieces of it in the top part of a lamp-funnel, which I place over a burning candle (Fig. 15), and put the whole on the scale and balance it. We won't need to wait very long.

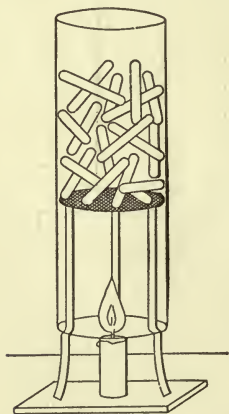


FIG. 15.

P. Yes, the scale with the candle is beginning to sink.

M. And the proportion will be more, the more the candle is burnt.

P. Is it the same with all burning substances?

M. Yes; you may try to burn, after this, oil, petroleum, or matches, or whatever else you like, instead of a candle, under the cylinder with caustic soda. The weight will always be increased.

11. OXYGEN.

M. What did you learn last time?

P. That all bodies become heavier by burning.

M. That is not quite complete. Think of the candle.

P. That all bodies become heavier by burning if you take what is formed into account.

M. Think of the candle again! If it was entirely burnt?

P. Ah, yes! That which is formed by bodies in burning is heavier than the body was itself.

M. Now it is right.

P. But can iron burn, too, so that nothing remains?

M. So that no iron remains? Certainly. Look, for yourself, what the iron powder that we burnt yesterday has become.

P. It is a dark mass, which looks rather like the powdered iron, only it is caked together.

M. Take some, and crush it in the mortar.

P. There is a black powder.

M. Now grind some powdered iron after you have cleaned out the mortar.

P. It is bright like iron.

M. Now you see the difference. The burnt iron isn't iron any longer, but a substance with other proper-

ties, and the iron has vanished in the same way that the burnt candle vanished.

P. But the air, which helped with the burning?

M. The same thing happened to it which happened to the iron. In the same way as the solid iron changed to the solid substance, smithy scales, the vanished part of the air used by burning a candle became part of another gas.

P. Has another gas been made by iron as well?

M. No.

P. Then air must vanish when iron burns in it.

M. We will make the experiment. I put my tripod with powdered iron on a little floating board, light it, and cover it with a large glass, so placed that it stands on the bottom (Fig. 16). As the experiment is rather

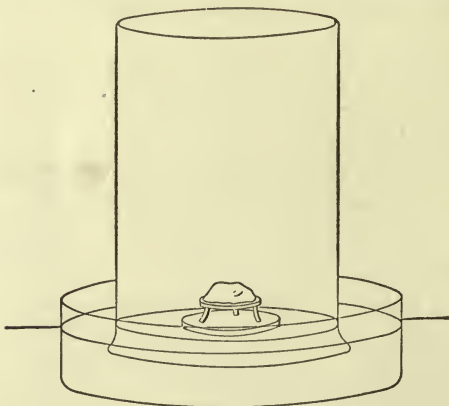


FIG. 16.

slow, we must wait till the glowing iron is extinguished and has become cold. What do you see now?

P. It really seems as if air had vanished; but only a part, less than a quarter.

M. If you measure it more closely, it is about a fifth.

P. Perhaps you took too little iron.

M. No. If I had taken more, no more air would have been used.

P. But this is quite different from a candle, and also from iron. You can burn them completely.

M. Can you burn wood entirely?

P. Ash remains.

M. It is the same with air. Wood is a mixture of combustible and non-combustible substances; when the former are burnt, the latter remain behind. Air is a mixture of two gases; the one gets separated by burning, and is called oxygen, the other is left unchanged, and is called nitrogen. Oxygen only takes up about a fifth part of the space of air.

P. If you had pure oxygen, would it entirely vanish in burning?

M. Certainly, if there were no other gas. We will make pure oxygen.

P. Can we?

M. It has been possible for rather more than a hundred years. This white salt is called potassium chlorate. When it is heated a great deal of oxygen is formed.

P. What sort of brown powder are you mixing with it?

M. That is heated iron-rust. When some is put with it, the oxygen forms more easily and regularly. I shake the mixture in a little round flask. Now I must make my apparatus. To do that, I take a cork which just fits into the neck of the flask, and cut a piece of glass tubing.

P. How can you cut glass?

M. It isn't exactly cut, but broken. But so that the fracture comes at the right place, and is even all round,

I must scratch, and divide the tube at the place I wish.

P. What sort of tool is this?

M. This is an old three-cornered file whose teeth are ground down so that three cutting edges are made. If I saw the glass tube with this sharp edge, it will crack. Then I break the tube apart with the crack furthest from me, so that it breaks off evenly (Fig. 17).

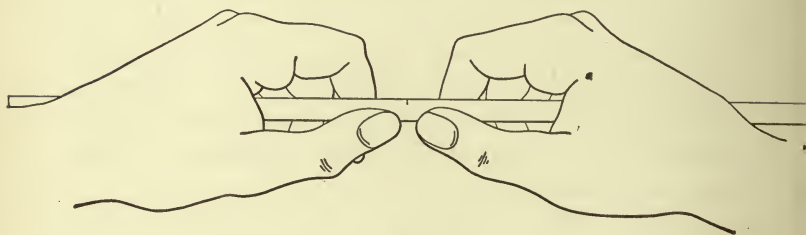


FIG. 17.

P. That is clever! Can I do it too?

M. I will give you a piece of glass tube afterwards and you can practice on it. Now I will bend the tube.

P. You can't; it will break.

M. Heat will make glass soft, so that it can be bent. I put the part where the bend is to come in the flame and turn the tube continually, so that it shall be evenly heated, otherwise it would crack. After a time the glass will become so soft that it will bend with its own weight. I help it a little till it is the right shape, and let the glass get cold and hard, then it will keep its new shape.

P. That looks so easy. Can I do it too?

M. It isn't difficult, but it needs practice. The main thing is, not to apply the heat to any one point, and only to use very light pressure in bending it. Otherwise

the bend may easily come uneven. Now the other end of the tube must be bent a little, and finally I turn each end in the flame for a little, so that the sharp edges become round and can't cut or scratch any more. That must never be forgotten.

P. How is that managed?

M. Soft glass behaves like liquids. You know that instead of having corners or points, their surfaces are always rounded.

P. Why do liquids do that?

M. On account of the surface tension. Through this the surface endeavours to become as small as possible, and as a ball is the form which contains the most contents with the least surface, all liquids try to form themselves into the shape of a ball.

P. But liquids take the form of the vessel that contains them.

M. Quite right. This comes from gravity, as they always try to get as low down as possible. Both causes work simultaneously on the liquid, but the gravity is generally far the stronger, and the shape of the water is most dependent on that. Now we must make a hole in the cork. For that I bore a hole with a steel point, an awl, and then I file it with a somewhat large round file till I can with a little force stick the glass tube through. Now everything is put together, and I fasten the apparatus, so that I can slip a piece of wire gauze below the flask and put the lamp under it (Fig. 18).

P. Why do you put the end of the tube in a dish of water?

M. To collect the gas. If I were to stick the tube in an empty flask, that is, one filled with air, and were to lead the gas into it, it would mix with the air, and I

shouldn't be able to see when the flask was full. So I fill the flask with water, and allow it to be displaced by the entering gas, holding the mouth of the flask over

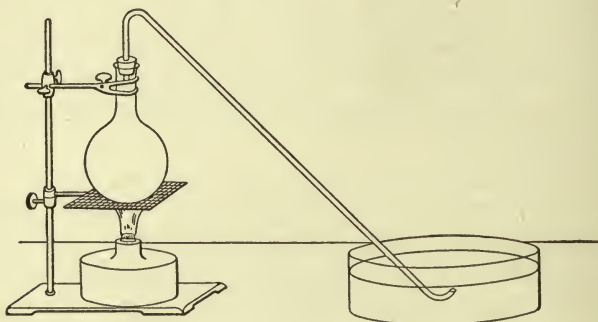


FIG. 18.

the glass tube. As the gas doesn't mix with water, I get it pure.

P. Bubbles of gas are rising; hold the flask over them!

M. At first it is only the air which was in the apparatus.

P. Then how do you know when the new gas comes?

M. I take the tube out of the water and hold a glowing splinter at its open end. What do you see?

P. It goes on glowing.

M. Then it is only air. And now?

P. Oh, it begins to burn of itself!

M. Not of itself, but with the oxygen which comes out. Now I bring the tube below the water again, and hold the flask over it. But in order not always to have to hold it, I place it in a little lead stand, below which the tube ends, so that the bubbles rise in the flask and expel the water (Fig. 19). In the mean time I will

fill some flasks with water so that we may afterwards fill them with oxygen.

P. Please show me the experiment with the glowing splinter again.

M. It is the test for oxygen. Whenever a glowing splinter is put into oxygen it catches fire. I can repeat the experiment often with the oxygen in this flask. But at last it gets used up, and the experiment won't succeed any more.

P. What is the reason of that?

M. I will first show you some other similar experiments. I tie a piece of charcoal on to a wire, light it at one corner, and place it in the oxygen. It soon begins to glow all over, much more brightly than in air. A bit of sulphur in a little iron spoon which you can hardly see burning in the air gives a bright blue flame. A piece of phosphorus in a similar spoon, which burns in the air with a yellow flame, looks as bright as the sun. A thin spiral of iron wire, on the end of which a little tinder has been fastened and made to glow, catches fire and burns, throwing out sparks, and the

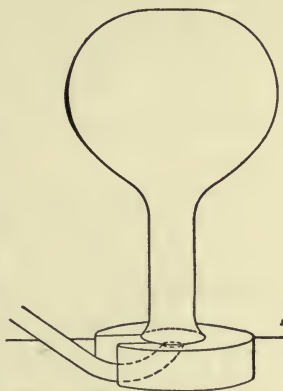


FIG. 19.

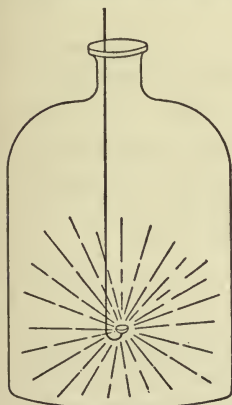


FIG. 20.

smithy scales fall, while hot, into the water which covers the bottom of the flask. It is better to put a little sand

at the bottom of the flask so as to keep it from breaking (Fig. 20).

P. Oh, that is a beautiful firework!

M. We won't forget what the firework means. What can you say in general about these experiments?

P. Things burn much more brightly in oxygen than in air.

M. Quite right. But they burn in air too, at the expense of the oxygen that is present. Where does the difference lie?

P. They give off more heat when in pure oxygen.

M. Your answer is right or wrong according to what you mean by the word heat. If you mean to say that the quantity of heat that 1 gram of carbon or iron gives out is greater when it burns in oxygen than when it burns in air, that is wrong. The quantity of heat is the same. But if you mean that the temperature rises higher, that is right.

P. I mean the temperature.

M. Of course you do! This is the reason. The same amount of heat which is given out in both cases has only to heat the resulting product of combustion when the substance burns in pure oxygen; but when it burns in air it has to heat the nitrogen which is mixed with the oxygen.

P. Is the brighter light connected with the higher temperature?

M. Certainly. The temperature can even be estimated from the brightness of the light. But, besides that, the higher temperature makes the burning take place more quickly.

P. What has that got to do with it?

M. It has been generally found that chemical changes

take place more quickly the higher the temperature. But we will go back to oxygen again. The phenomena you have seen are all chemical changes, for the burning substances and the oxygen have disappeared, and new substances have been produced instead.

P. Are the heat and the light which have been produced, new substances too?

M. No, these things are not called substances, because they possess neither weight nor mass.

P. But all the same they are really there.

M. Certainly, because they are real things. They behave something like substances, for they change into one another, and new quantities of them can never be produced except by such change. Only they have no weight like substances.

P. Then these must be what are called forces?

M. People used to call these things forces, but that led to a misunderstanding, since the word force had already been used for something different. Now they are called energies. Heat is one kind of energy, and light another.

P. Yes; people are said to be energetic who can do something and carry it through.

M. The scientific use of the word energy is pretty nearly the same. Energy is what causes things to change.

P. So when substances change by chemical action, is that energy too?

M. To be sure; only we express it somewhat differently. We say that substances possess chemical energy when they are able to act on each other and produce new substances. At the same moment that the substances change, a change of a part of their chemical energy

takes place, and this assumes the form of heat or light, and sometimes of electrical or mechanical energy.

P. That strikes me as very curious and mysterious.

M. The change of one kind of energy into another is not more mysterious than the change of one substance into another; indeed, it is even simpler. To tell you a little more about energy: you must know that the ordinary work which a man or a horse or a steam-engine does is also energy.

P. Then I ought to be able to make heat or light or electricity by my arms.

M. So you can; when you rub your hands together they grow warm, and if you turn a blunt drill with all your force in a hole, it soon becomes so hot that you could burn your finger with it. And you know already that people can make fire by friction.

P. Yes, that is true. So I can make as much heat as I like?

M. Not as much as you like, but as much as you can. When you turn the drill for some time you can't go on any more; you are quite exhausted; that is, you have used up the store of energy which you possessed.

P. Where did I get that energy from?

M. From your food. It is chemical energy which you have taken in with your food, and in your body there is a kind of apparatus, the muscles, which change chemical energy into work.

P. How do they do that?

M. I wish I knew! Investigators haven't found out yet how it is done. But there is no doubt that chemical energy is used up in doing work, for you see that a hard worked horse must be well fed in order to do its work.

P. But I always have a good appetite, even when I do nothing.

M. Then you waste the chemical energy of your food. Of course you always want a certain quantity in order to keep your temperature up to 37° C.; for as your body is considerably warmer than its surroundings, it is continually losing heat which must be replaced by means of food. That is a second way in which you can make heat, although it is beyond your control.

P. Can I make light too?

M. Yes; if you rub two pieces of sugar together in the dark, they will make light.

P. Don't they make light in the daytime?

M. Yes; only the light is so weak that it can't be seen by daylight. This experiment shows that the work of your muscles can be changed into light.

P. But can't I make light without anything?

M. *You* can't; but glow-worms and little animals, which are the cause of the phosphorescence of the sea, can. These change the chemical energy of their food directly into light.

P. And can I make electrical energy too?

M. Certainly; you have only to rub a piece of sealing-wax with a cloth.

P. Oh, yes, I know. But I must use my muscles again to do that; I don't do it directly.

M. Electric currents run through your body whenever you exert yourself, indeed whenever you think. But they stay in your body and it isn't easy to conduct them outside.

P. I never dreamt that I could do all these things!

M. Well, you needn't be conceited about it, for every animal can do the same.

P. Still, it's very queer. Where does the energy of food come from?

M. From the sun.

P. I don't understand that.

M. Where does food come from? Either from plants or animals. Plants grow only in sunlight, for they use the energy of light to build up their structures; they store it up in this form. And we consume the energy of the sun in the plants. And the animals whose flesh we eat subsist upon plants, that is, upon the energy of the sun.

P. I shall think of the sun quite differently after this.

M. If you only think of what we have been speaking about, you will understand more of the world than you did.

12. COMPOUNDS AND CONSTITUENTS.

M. Last time you learned a great deal that was new to you. Tell me the principal things.

P. First I learned how oxygen is made and collected; then I learned that substances burn far more brightly in it than in ordinary air, and that is because air contains only a fifth part of oxygen. Then I learned something about energy. But that was so much and so unfamiliar that I can't say it in a few words.

M. We will try together. Wherein does energy resemble substances, and wherein does it differ from them?

P. Resemble? Yes, it can change into many kinds, and when one kind is formed, others vanish.

M. Right. Where do they differ?

P. Energy can't be weighed, and it comes from the sun on to the earth. Substances don't come from there.

M. No, at any rate not in detectable quantity. Now, first of all, be sure of these points; the others will be much more comprehensible if we are careful over these. Now we will return to oxygen. There is still here a flask which was filled yesterday. What noticeable properties has it?

P. Oxygen looks like air; it is colourless.

M. What does it smell like?

P. I can't smell anything; it has no smell.

M. You should have been able to tell me that without opening the bottle. Just think, a fifth part of the air is made of oxygen.

P. Oh, yes, because air doesn't smell, oxygen can't.

M. These are the noticeable properties of oxygen. Besides these it has others, which can only be found out by measurements or experiments. The burning phenomena that I showed you are also such properties. They are called chemical properties, because they depend upon chemical processes. Also the reaction of oxygen, the bursting into flame of a piece of glowing wood, is one of these chemical properties. Now we will learn another way of telling oxygen. This brick-coloured powder is called mercuric oxide. I put some into a test-tube made out of a particular kind of glass that has rather thicker sides, and is more difficult to melt than ordinary glass, and attach a gas-delivery tube as before. Then I make the glass hot with a lamp. What do you see?

P. The red powder is becoming black. It is becoming charred.

M. No; if I let it get cold it will become red again.

P. Then how does it get black?

M. There are many substances which change their colour with heating. Colour depends to a great extent on temperature.

P. Now there are bubbles coming (Fig. 21).

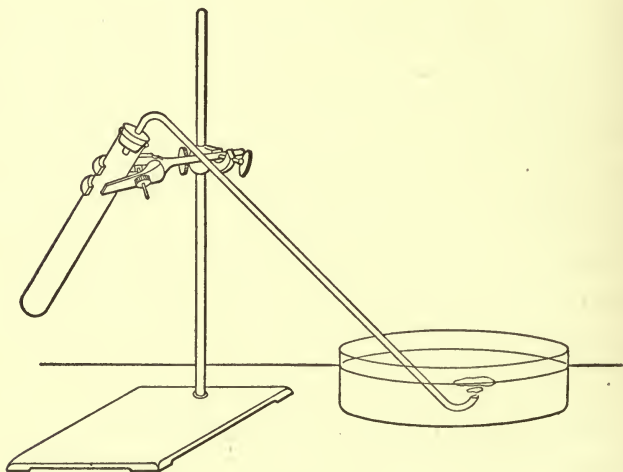


FIG. 21.

M. Again it is, first of all, air which has expanded by heat.

P. But now the bubbles are much more frequent and continuous.

M. We will collect some of the gas in a little test-tube and try it with the glowing splinter. It is still air that is coming out of the test-tube. But the second time it is filled—

P. The splinter has caught fire; it is oxygen.

M. Perhaps. We will collect some and see if it is colourless and scentless. Try it!

P. Yes, it is scentless, and one can't see any colour. But why was it necessary to prove it in this way as well?

M. Before one can say that anything that one has is a definite substance, one must have made sure that all its properties are the right ones.

P. But then, one can't look for all its properties; there would be no end to it.

M. There you are right. But several properties must always be tested for, because it often happens that different substances have one common property, whereas other properties are different.

P. Really just the same property?

M. One can't be absolutely certain, even when no difference can be seen. Since no property can be noticed, or measured with absolute exactness, one can't be certain that a seeming resemblance will not turn out to be a difference on closer inspection. But just to make these difficult researches unnecessary, people examine several properties. For it is very seldom that two different substances have several properties in common.

P. Look what has happened to the experiment meanwhile. The test-tube looks just like silver at the top.

M. Yes, and the greater part of the mercuric oxide has disappeared. I heat it a little longer and now it is all gone. I take the delivery-tube out of the water and let everything cool.

P. Why don't you leave it all as it is?

M. The hot oxygen gas in the tube in cooling would contract, and the water might enter the test-tube. Now look closely: the silvery stuff in the tube can be brushed together with a feather, and changes into bright liquid droplets.

P. They look just like mercury.

M. They are mercury.

P. But how did it come there?

M. It came out of the mercuric oxide.

P. And has the oxygen been made from it too?

M. Yes, these two substances, and nothing else.

P. But why isn't the mercury where the mercuric oxide was?

M. Because the mercury with the heat from the lamp became volatile, that is, it changed to a vapour. Then, when the tube was colder, the vapour changed back again to liquid mercury. I will now take some more mercury in a test-tube, and heat it; look, the first drops are forming, it is becoming thicker, and now it looks like a silver looking-glass. I repeat the experiment with the liquid metal that I made before; you see it behaves just the same; it is mercury too. But take care of the vapour; it is poisonous.

P. I shouldn't have thought so!

M. Why not?

P. Mercury is a metal, and metals don't boil.

M. Certainly they do, only the boiling-point of most of the best-known metals lies so high that it can't be reached by ordinary means. But, for example, in the flame of the electric arc all known metals turn to vapour. Mercury, however, boils fairly easily at 350°C . But now we will go back to our experiment. You saw that by heating, the red powder changed into mercury and oxygen. Out of mercury and oxygen red mercuric oxide can be made again. You can, so to speak, reverse the reaction.

P. That is wonderful. Can I see it?

M. Unfortunately I can't show you. Mercury oxide is formed out of mercury and oxygen, if they are left in

contact together at a temperature something over 300° . But that takes place so slowly that it would take a week to get a couple of grams. But if it is done it shows exactly the same properties as mercury oxide.

P. Isn't it made in that way, then?

M. No, it is made in quite a different way, which you wouldn't understand yet.

P. Then it doesn't matter which way it is made?

M. Certainly; there is an important general law, that a definite substance always has the same properties in whatever way it may have been made.

P. I shouldn't have thought so!

M. You have just had an example of it: the oxygen made from mercuric oxide had exactly the same properties as that made from potassium chlorate.

P. Yes, so it did. I never thought of that; I took it for granted.

M. You see again: People take things for granted when they don't think about them. Now notice some new names; because from one single substance, mercuric oxide, two different substances, mercury and oxygen, can be made, and vice versa; from the two latter, again, a single substance, mercuric oxide, can be made; the latter is called a compound and the former the constituents. So mercuric oxide is—?

P. Mercuric oxide is a compound of mercury and oxygen.

M. Yes, and mercury and oxygen are the constituents of mercuric oxide.—Now we are coming to an important question about the proportions by weight in chemical processes. In this closed flask there is oxygen, and there is a piece of charcoal hanging from a wire in it. I weigh

the flask on the balance. Now I will light the charcoal without opening the flask.

P. How will you do that?

M. I could do it in several ways. If I had put a second wire through the stopper, and bound both wires together with a thin piece of iron wire, I could make it glow with an electric current, and it would light the charcoal. But since we have sunshine, I can do it in a far simpler way: I shall light the charcoal with a burning glass.

P. Good; that's splendid. Hurrah! the charcoal is burning already.

M. And now it has gone out again, since the oxygen is used up. Now what do you think; will the flask have become heavier?

P. Of course.

M. You have taken it for granted again! But we will look. What do you see?

P. The pointer is going backwards and forwards over the middle. The weight seems to have remained the same. Perhaps the increase is so little that it can't be noticed?

M. No, even with the most careful weighing it would always be the same.

P. But that can't be right! I learned and saw that weight increased with burning.

M. The weight of what?

P. Ah! so it was. The product of combustion weighed more than the burnt body weighed.

M. Well, and here?

P. Here it weighs the same.

M. That is a false conclusion. It really weighs more.

P. But then, how is it that the weight didn't change?

M. It is because the oxygen disappeared. The product

of the burning weighs just as much more as the used oxygen. So the gain and loss have balanced each other.

P. That is extraordinary.

M. Yes, it is an example of one of the most important laws, which holds for all chemical, and also for all physical, processes; *whatever changes take place between definite substances, they never change their combined weight.*

P. But the separate weights change?

M. Certainly; but what the one side loses, the other gains. The law only refers to the sum of all the weights.

P. You always taught me, in cases like this, never to ask why it is so, but with what it is connected. Is anything known about it?

M. Certainly. You know that weight and mass are in every place proportional. So also the law of the unchangeableness or conservation of mass holds.

P. What is the use of this law?

M. It makes it possible to account for proportions by weight in chemical changes even when you cannot, or do not want to, weigh each substance separately. For example, if I weigh the amount of mercuric oxide I take, and the amount of mercury I get from it, then I know how much oxygen was there too. Because there must always be this equation: Mercuric oxide = mercury + oxygen, where the name of the stuff denotes its amount by weight.

P. Has oxygen a weight? It is a gas!

M. Do you think that gases have no weight?

P. I can't believe it.

M. The density, or the relation of the weight to the volume, is small with gases, several hundred times smaller than with water. But they certainly have weight. One litre of ordinary air weighs more than one gram.

P. I'd like to see that.

M. I can show you quite easily. Here is a flask of strong glass which I close up with a stopper, in which there is a glass stop-cock. So that it shall not get pulled out, I tie it firmly down with wire or string. Now I shall weigh it all. I can pump air into the flask through the open stop-cock with a bicycle pump. After pumping twice, I close the stop-cock, put the flask again on the balance, and it has become distinctly heavier.

P. Can you see how much air you have pumped in?

M. Yes; with the aid of a little rubber tubing I connect the delivery tube from the oxygen apparatus with the stop-cock, put a flask filled with water over the end, and now, if I open the stop-cock, the air which I pumped in will come out, and collect in the flask (Fig. 22). If you

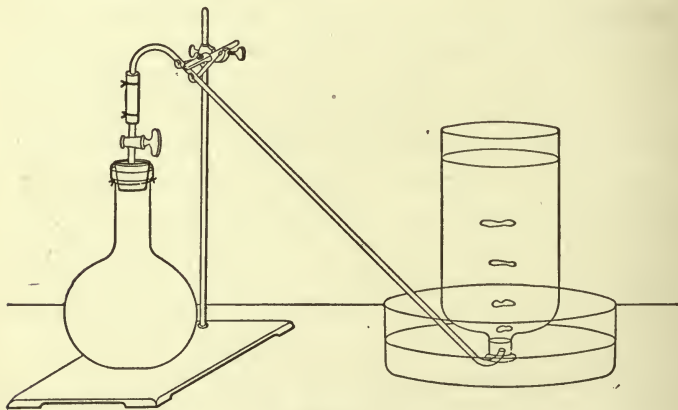


FIG. 22.

had weighed the flask exactly before, and weigh it again now, the loss of weight is the same as the air that has just come out. And if you know the capacity of the flask, you can measure the volume of the air.

P. Yes, so you can!

M. After this you may try to measure like this; you will find that air is about 800 times lighter than water. Now we will go back to our experiment. Have you noticed the amount of oxygen I got from potassium chlorate and mercuric oxide?

P. Yes. There seemed to be far less from mercuric oxide.

M. Yes. One gram of potassium chlorate gives far more oxygen than one gram of mercuric oxide. But if I make the experiment twice, each time with one gram of mercuric oxide, what will be the result?

P. Each time it will be the same.

M. And with potassium chlorate?

P. The same.

M. You think, then, that if a substance is changed into another, this always happens according to definite proportions by weight.

P. I don't know whether it is quite definite, but it must be so, more or less.

M. It is exactly so. You could have thought of that before. For a definite substance has always quite definite properties; its capacity, in certain cases, to change into another substance, is one of these properties; it follows that the ratio of the weights of the original stuff and of the product of change must be definite.

P. I should never have had the courage to draw such a conclusion.

M. How can it be proved that such a conclusion is right?

P. By experiment.

M. Right. Now experience has shown for several hundred years that between the substances which take

part in any change, roughly speaking, a definite ratio must exist; from a pound of fat an unlimited amount of soap cannot be made, but somewhere about the same, and so on. But it is only in the last one hundred years that this question has been carefully tested and the law found to be quite exact.

P. Does it apply to all substances?

M. To all pure substances; that is, to those that are neither solutions nor mixtures.

P. It is strange. The laws which you have taught me up till now are all very simple and easy to understand. But I'm afraid I will never be able to understand and use them at the right time.

M. That is only natural. A law is like a tool: if you have had no practice, it is of very little use having the tool, even if you know what it is for. But what we are going to talk about later on will give you the necessary practice.

13. ELEMENTS.

M. Last time you learned two important laws, which show the relation of the proportion by weight of such substances between which chemical changes take place. The one was called the law about the conservation of weight; just say it over!

P. If chemical changes take place between given substances, the combined weight is not changed by it.

M. And what is the other law about?

P. About the proportion of weight in chemical changes. If one substance changes into another, the weight of the one has a definite ratio to the weight of the other.

M. Right. It is called the law of constant proportion.

P. But what connects these ratios?

M. That is a sensible question! I can give you a very wonderful answer for it. But to do that I must first make a new idea clear to you: that of chemical elements. You remember the equation: Mercuric oxide = mercury + oxygen; what sort of quantity was concerned?

P. That of weight.

M. Now, if you split up a definite quantity of mercuric oxide by heat, and collect the mercury, will it weigh more or less than the mercuric oxide?

P. Let me think a minute. It must weigh less.

M. Why?

P. Because it weighs as much as the mercuric oxide, with the oxygen, and oxygen has weight too.

M. Right. Then if mercury is made into mercuric oxide, or oxygen into mercuric oxide, in each case weight is added: in the one case, the needed amount of oxygen, in the other case, of mercury.

P. I understand that.

M. You remember also that we called oxygen and mercury the constituents of mercuric oxide, and the latter a compound of the former.

P. Yes.

M. Then it follows that a constituent must always weigh less than any of its compounds.

P. Because something is added each time.

M. Quite right. Now you can believe that all sorts of chemical experiments have been made with oxygen, like the one you have seen, and that every time the weight of the new substance, which was the result of the consumption of the oxygen, was determined. No single instance has been found in which one of the resulting

substances weighed less than the oxygen it contained. All weighed more.

P. Then oxygen can only form compounds?

M. Yes, and no constituents of oxygen are known. Substances of this sort are called elements. What is an element?

P. A substance, all the products of change of which weigh more than it does itself.

M. Quite right. It can also be said that an element is a substance of which no constituents are known. But this definition is not so clear, because it must first be known what a constituent is.

P. But I learned before that an element was an undecomposable substance!

M. It means the same thing. The changing of a substance into its constituents is called decomposition. Because, out of a single thing, several different ones arise, such a process is called decomposition.

P. Now I understand. But to decompose means to separate what is already there, not to change it.

M. It is like this: If a definite amount of mercury and oxygen has changed, or united into mercuric oxide, it is true that the mercury and oxygen have vanished, but they can be obtained out of it again at any time. And exactly the same amount of each constituent is obtained as was originally there. You can look at it in this way: as if both the constituents in the compound were still really present, and had hidden themselves, as it were, when they combine with each other. Hence the expressions decompose and combine.

P. Yes; which is true then? Are the constituents really in the compound still, or not?

M. You asked that question without thinking. A

compound isn't a bag or box in which something can be "in." If you understand by "in" that by suitable means they can always be taken out of the compound, they are in it. But if you mean that they are hidden away somehow in the compound with all their properties, that wouldn't be clear and would be misleading. You know now what I mean when I say oxygen is an element.

P. Are there more elements?

M. Certainly, mercury is one too. Sulphur, iron, tin, lead, and copper are also elements. There are altogether about seventy-five different elements. Here is a table of elements (see on the next page); if you look through them you will see some friends. But most of them are unknown to you. A great many of them also are very rare, that is, the substances out of which they can be procured are rarely found.

P. Can't the rare elements be made out of other substances which are more frequently found?

M. No, that can never be the case. A given compound can only be divided up in one way into elements, that is, from every substance only definite elements can be obtained, and however one may try, the same elements are always found in the same proportions. And to make this substance artificially, just the same elements must be taken in the same proportion, or compounds must be made use of from which these elements can be got, or in which they are "contained."

P. Is that another law of nature?

M. Yes, it is the law of the conservation of the elements.

P. Please explain it a little more.

Aluminium.....	Al	Neon.....	Ne
Antimony.....	Sb	Nickel.....	Ni
Argon.....	Ar	Niobium.....	Nb
Arsenic.....	As	Nitrogen.....	N
Barium.....	Ba	Osmium.....	Os
Beryllium.....	Be	Oxygen.....	O
Bismuth.....	Bi	Palladium.....	Pd
Boron.....	B	Phosphorus.....	P
Bromine.....	Br	Platinum.....	Pt
Cadmium.....	Cd	Potassium.....	K
Cæsium.....	Cs	Praseodymium.....	Pr
Calcium.....	Ca	Radium.....	Ra
Carbon.....	C	Rhodium.....	Rh
Cerium.....	Ce	Rubidium.....	Rb
Chlorine.....	Cl	Ruthenium.....	Ru
Chromium.....	Cr	Samarium.....	Sa
Cobalt.....	Co	Scandium.....	Sc
Copper.....	Cu	Selenium.....	Se
Erbium.....	Er	Silicon.....	Si
Fluorine.....	F	Silver.....	Ag
Gadolinium.....	Gd	Sodium.....	Na
Gallium.....	Ga	Strontium.....	Sr
Germanium.....	Ge	Sulphur.....	S
Gold.....	Au	Tantalum.....	Ta
Helium.....	He	Tellurium.....	Te
Hydrogen.....	H	Terbium.....	Tb
Indium.....	In	Thallium.....	Tl
Iodine.....	I	Thorium.....	Th
Iridium.....	Ir	Thulium.....	Tu
Iron.....	Fe	Tin.....	Sn
Krypton.....	Kr	Titanium.....	Ti
Lanthanum.....	La	Tungsten.....	W
Lead.....	Pb	Uranium.....	U
Lithium.....	Li	Vanadium.....	V
Magnesium.....	Mg	Xenon.....	X
Manganese.....	Mn	Ytterbium.....	Yb
Mercury.....	Hg	Yttrium.....	Y
Molybdenum.....	Mo	Zinc.....	Zn
Neodymium.....	Nd	Zirconium.....	Zr

M. You know that some time ago there were chemists who gave their whole life trying to make gold or silver out of lead or other cheap metals, without one of them succeeding; they were called alchemists. Now, the whole of alchemy was built upon the hope that it was possible to change one element into another, perhaps lead into gold. It could not be foretold that this was not possible; it was only by resultless efforts continued

through centuries, that it was found to be impossible in the case of gold and silver, and, later, in the case of all other elements.

P. Then the gold-making wasn't so mad and useless in the long run?

M. Neither the one nor the other. It wasn't mad, because it became known that it couldn't be done. Only the gold-makers didn't work scientifically, that is, in an orderly manner, because they only tried things on chance. And the final result—that elements could neither change into each other, nor the compounds of definite elements into the compounds of other elements—was an important scientific discovery, which made the study of chemistry far easier.

P. I don't understand that.

M. Just suppose that if we provide each element with a definite sign, then we can mark every compound by putting the signs of their elements together. Just as you make the word "hat" out of only the signs h, a, and t put together, and it can only be divided up into these signs, and you can never build up the word "rose" out of these signs, so compounds and elements act in the same way. In the table of elements (page 96) there is a sign like that, against every name, that is made from the first letter of the name, and generally a second letter as well. Every substance that is on the earth can be represented by placing together such signs, for however many substances there are, every one of them can be decomposed into elements only in its own particular way.

P. I see, it is again one of those laws which are really very simple, only you must be accustomed to them first.

M. You will soon get accustomed enough to them.

In the mean time we will take our table of elements and see how much chemistry you know already from daily life. Oxygen you know already; it is a colourless gas. Hydrogen is a colourless gas too, but combustible.

P. What is hydrogen?

M. An element that can be obtained from water.

P. Then isn't water an element?

M. No, it isn't in the table. It is a compound of oxygen and hydrogen. You know something about nitrogen too; it is the other ingredient in the mixture of ordinary air. It is also a colourless and tasteless gas.

P. Yes, because air is.

M. Right. Now comes carbon. It isn't a gas, but a solid body. Ordinary charcoal consists of carbon, but not in the pure state. These four elements are always in all living things, plants as well as animals, and as such form a definite group. That is the reason I named them first to you. Moreover they are the type of four different groups of other elements.

P. What does that mean?

M. Among the other elements there are a number which behave in the same way as oxygen, while others are more like hydrogen, others like nitrogen, and again others like carbon.

P. What do you mean by "like"?

M. They have to some extent similar physical properties in an uncombined condition as so-called free elements. In many cases also the compounds which are formed with a third or fourth element are like in their properties.

P. That doesn't appear to me a definite reason for classifying them.

M. Neither it is. But by taking into consideration

all the properties of all the compounds which can be produced from an element, so many resemblances and differences turn up that a chemist who knows the relationships doesn't find the choice difficult. As you don't know them yet you must simply accept my classification.

P. But it appears to me to be unscientific to accept anything that I can't prove.

M. You will be able to prove it when you have learnt enough chemistry. Besides I won't use the classification for any scientific conclusion, but only for your own convenience, so that you can learn the facts more easily; besides, such arbitrary things can be treated in science in an arbitrary manner.

P. Yes I see.

M. Now impress the following names on your mind:

* Hydrogen	* Oxygen	* Nitrogen	* Carbon
* Chlorine	* Sulphur	* Phosphorus	* Silicon
* Bromine	Selenium	Arsenic	Titanium
* Iodine	Tellurium	Antimony	

Later on we will study carefully only those elements marked with an asterisk.

P. Why only these?

M. The others are either too seldom found in nature, or their compounds have too little importance in their applications. As we can't learn nearly all that has been found out up to the present in chemistry, we must be satisfied with a selection. I arrange this so that at any rate you learn the substances which on account of their uses, or on account of their sources, come most frequently before our notice.

P. Then I am only to learn a little part of chemistry?

M. There are very few people who know every fact that has been proved in chemistry up to the present. I shall try to teach you those parts of chemistry that will

give you the best conception of the most important relations. Later you can take up a special branch, which you can learn as thoroughly as you wish. But now we will speak about the elements we have chosen. I have already told you about hydrogen, that it is a colourless, combustible gas; but its flame is quite pale and gives very little light. It is the lightest substance there is, and for that reason is used for filling air balloons.

P. Is there hydrogen in the little red india-rubber balloons that children play with?

M. Certainly, and if one of these freshly filled balloons is set fire to, the hydrogen burns with a puff.

P. I will try that next time.

M. But don't hold it too near your face, or you may burn yourself, for the flame is hot, and it often goes off with a tremendous bang.—Chlorine is a greenish gas, with a very unpleasant, pungent smell. Perhaps you have already smelt it, because a white powder called chloride of lime is often scattered on unpleasant-smelling decomposing matter; its smell is that of the greatly diluted chlorine.

P. Yes, I remember; our boy always strews it at the street corner. Why do people do that?

M. The chlorine destroys the bad-smelling substances and kills the offensive little germs or mould or bacteria.—Bromine is at ordinary temperature a deep reddish-brown coloured liquid, and has a yellowish-red vapour which smells the same as chlorine.

P. Ah, then that is one of those resemblances of which you spoke.

M. Yes. Iodine smells like it too, only at ordinary temperature it is a solid, shiny, black substance, the vapour of which is violet.

P. I remember that my throat was painted with tincture of iodine once. Has that anything to do with the element iodine?

M. Yes, it is a solution of iodine in spirits of wine. With that we finish the first group. Of the second you already know oxygen. And sulphur is familiar to you too.

P. The yellow stuff?

M. Sulphur is a solid substance of a yellow colour, and burns with a blue flame.

P. And in doing so gives off a very bad smell. Why do most substances in chemistry smell so queer and unpleasant?

M. The bad-smelling substances are mostly those which have a corrosive effect upon the inner skin of the nose. If they didn't smell badly, we wouldn't notice anything, and we would always have a sore skin and a cold in our noses. Chemistry would be a far more dangerous thing to work with than it now is.

P. Ah, that is good. Do all poisonous substances smell nasty?

M. First of all, we can only smell those substances that change into gas or vapour, because otherwise they would never reach our noses. Fortunately most poisonous substances have a bad smell, especially the corrosive ones. Still there are some poisonous gases and vapours which have none, or only a very faint smell. They are especially dangerous. We will learn about one of these gases later on.

P. Then I'll take care.

M. We will go now to the nitrogen group. You know a little about this already. It is not poisonous, because we breathe it together with the oxygen in the air. But in pure nitrogen, without any oxygen, animals must die,

because they require oxygen to live. You know something about phosphorus too.

P. Yes, it is in the heads of matches.

M. Right. From that you know one of its properties. It catches fire very easily; even the heat resulting from friction makes it do that. That is why it is used in matches.

P. I saw in the dark lately, that the heads of matches shone; there was a pale-green light, and the cook told me it was because the matches had become damp. How is that possible?

M. Phosphorus burns slowly if it is left in the air, and in doing so shines as you saw. So that the small quantity of phosphorus, which is contained in a match's head, shall not burn of its own accord, the phosphorus is mixed with gum, or lime, which dries, and forms a covering that keeps oxygen out. In the damp this covering is dissolved, and the phosphorus comes in contact with air.

P. Yes; but when I wet a match in the room later, it didn't shine.

M. That must have been a so-called Swedish match; they have no phosphorus in their heads.

P. What does phosphorus itself look like?

M. Almost like wax. It is kept under water, because it burns slowly away in air, as I said before. Since it is very poisonous, it is better I should not give it to you in your hand.

P. How is it made?

M. You think you could make it for yourself without my permission! No, that isn't so easy. It is one of the ingredients of bones, and is separated in a rather complicated way.

P. How can it be in bones if it is so poisonous?

M. Phosphorus as a free element is poisonous, but its compounds are not. There you have another example of how different elements and their compounds can be.—Now we come to the last group. Besides carbon, which you already know, you must learn about silicon.

P. Does silicon come from the Latin *silex*, flint?

M. Yes; flint consists of a compound of silicon and oxygen; it is usually called *silicic acid*. Quartz, sandstone, rock crystals, and flint consist of it. Finally, almost all rocks are compounds of silica, so that the element silicon is one of the substances that are found in the greatest quantity on the earth's surface.—Now that will do for to-day. I will only say that the elements mentioned now go under the name of non-metals. They form the larger division of the elements; the other consists of metals.

P. I think I've learned a great, great deal to-day.

M. That was only a walk through our future work. The real learning comes later.

14. LIGHT METALS.

P. How many different sorts of metals are there?

M. About sixty. As we do not know enough about some, the number is rather uncertain.

P. But how can you find your way among such a large number?

M. In the same way that you can find your way amongst the much larger number of animals and plants: they are divided into groups, in which those which resemble each other are put together.

P. They do that with animals and plants according to their shapes and organs; that can't be done with metals.

M. That is not quite right; the crystals which form when different elements are in their solid state show some resemblance, like the shapes of plants and animals. But metals have other properties which are remarkably different among each other, while organized beings resemble each other pretty closely; those are their *chemical* properties or their capacity to form compounds with other substances. Besides that, their physical properties, lustre, colour, density, hardness, and so on, are very different.

P. Then I must know the properties of all the elements I am to learn about, if I am to understand and remember their classification.

M. You need to know first of all only those which lead up to, and complete, the classification. At present you only need to know that the elements which I place in one group possess definite resemblances in their properties.

P. Yes, that is true. What properties are the basis of classification?

M. They are very different. It happens that the groups which have been placed together because of one definite property are almost always those which would be made because of other properties. So the present usual grouping is the result of quite a number of these selections of properties. Those which, in each group, have similar properties will be explained to you separately later.

P. So there is a perfect order?

M. Almost, to the same extent, as there is order among plants and animals. There, too, there are doubtful

points, either because the difference is too little or because different methods of classifying lead to varying classification.

P. But it can't be that in such unchangeable things as the properties of elements there can be contradictions?

M. There are no contradictions in the properties, but the irregularities of the somewhat arbitrary arrangement that we have made—

P. Yes; then why isn't everything simply arranged as in arithmetic or geometry?

M. For this reason: we have only incomplete knowledge of the properties of the elements. Most of our experiments, for example, are made at temperatures which are not very different from that of a room, and under ordinary atmospheric pressure. Our conceptions of the properties of the elements would be quite different if we knew how they were affected by all sorts of pressures and temperatures.

P. Then the imperfection of the classification is only due to the incompleteness of our knowledge?

M. That is quite possible, for experience has shown up till now that a department of science becomes clearer and more easily surveyed, the more exact and all-embracing our knowledge becomes. But now we will go back to our subject. We will divide metals into light metals and heavy metals.

P. What is the meaning of light metals? All substances have weight, and so are heavy.

M. Quite right. Those metals whose density is less than four times that of water are called light.

P. Why was four made the limit?

M. Because the other properties of metals are such, that by making a limit here, it made their differences

most clear. This is a case of the mutual help of distinguishing marks that I mentioned before.—Light metals fall into three groups: the alkali metals, the metals of the alkaline earths, and the metals of the earths. These groups contain the following important elements:

Alkali Metals.	Metals of the Alkaline Earths.	Metals of the Earths.
Sodium	Magnesium	Aluminium
Potassium	Calcium	

P. But those are very few.

M. They are by no means all. But I won't mention the others just at present, because either they are so seldom found, or have so little importance in their uses, that you needn't bother yourself about them just now.

P. Is the aluminium which you have named the well-known white metal?

M. Yes, and if you have had a piece of it in your hand you will remember that it is extraordinarily light. It is, in fact, only 2.7 times heavier than water.

P. Yes. Aluminium really is a light metal. But is it true that it is made out of earth?

M. It is half true; only earth is not a definite chemical substance, but an accidental mixture of all sorts of rocks and their products from decay and time. But in nearly all rocks and earth aluminium is found in the form of a compound with oxygen. The different sorts of loam and clay especially contain the element aluminium.

P. Ah, that is why it is called a metal of the earth. But if it is so common, why is it so expensive?

M. It isn't so very expensive now; one pound costs about twenty-five cents; that it is so much more expensive than the substances it is obtained from is because it requires a great deal of work to separate it from its

compounds. It was hardly known before the electric current began to be used. The difference of price between aluminium and its compounds, then, shows the greater amount of work or energy which is contained in the element aluminium, than in the compounds from which it is prepared, and as you know work is never given as a present.

P. Can you get the work out of the aluminium again?

M. Certainly. Here is a mixture of aluminium with a compound of iron, iron oxide, which you already know. If I light this mixture an immense amount of heat is given off, the mixture glows white hot, the metal iron is set free, and all sorts of welding and melting can be done with the hot mass.

P. That is a pretty experiment. How was the mixture made?

M. Aluminium powder and iron oxide are mixed in the proportion of 1 to 3. Both substances must be thoroughly dried beforehand by heat. The lighting is done with a small piece of magnesium ribbon (you will soon learn about magnesium itself), which is made to burn by means of a match. The mixture is placed in a clay crucible, or in a cavity, which you can make in a dry brick.

P. What happens exactly?

M. Iron oxide, as you knew, is a compound of iron and oxygen. If aluminium comes in contact with it when hot, it unites with the oxygen, and the iron is separated; as through the uniting of oxygen with aluminium much more work is set free than is necessary to separate oxygen from iron, a great amount is left over, which appears as heat.

P. Is work the same thing as heat?

M. In so far as the one can be changed into the other. You can tell that work changes to heat because, by friction, heat is obtained. And to overcome friction, work is necessary.

P. Yes, now I know. And a steam-engine makes work from heat.

M. Right. But now we must go back to our light metals. Of the metals of the alkaline earths you probably already know magnesium.

P. Isn't it magnesium that burns so brightly?

M. Yes, magnesium is a light white metal, which can be lighted, and burns with a bright flame. It is used when a bright light is required and no electrical current is at hand. For that purpose it is generally made in the form of a narrow strip or ribbon. Here is such a piece of magnesium ribbon that is brought in this form into commerce. I light it, and you see how brightly it burns.

P. What is the white ash and the white smoke that comes from it?

M. That you ought to know for yourself. What is combustion?

P. A combination with oxygen. Then is the white stuff an oxide of magnesium?

M. Yes. And the strong light is another example that in this combination between oxygen and magnesium there is a great deal of surplus work which shows itself as light and as heat.

P. Then is light a sort of work?

M. Yes, certainly. You know that plants grow and increase in light and form wood, leaves, and so on. The wood you can burn and obtain heat from, as a sign that there is work in it. This work has come from the light of the sun, because plants can only grow in light.

P. Where is magnesium found?

M. Like aluminium it must be obtained from its compounds by means of electric work. In nature, compounds of magnesium, generally with oxygen, occur in very large masses. Dolomite, which forms large mountains, is rich in magnesium compounds; they also occur in nearly all rocks.

P. What is magnesia that is used as medicine? Has it anything to do with the metal magnesium?

M. Yes, it is magnesium oxide, the same substance which is formed on burning the metal. The medicine, Epsom salts, is also a compound of magnesium. All these substances you will learn more about later on.

P. I should really like to have heard more about magnesium: there are so many sorts of things connected with it.

M. You will find the same thing with other metals. Calcium, for example, as a metal, is very little known, because it takes far more work than magnesium does to separate it from its compounds, and it burns far more easily.

P. Why should I learn about it now?

M. Because its compounds are extraordinarily extensive; it belongs to the elements in which the earth's surface is richest. Limestone, of which large mountains and countries consist, is one of its compounds; chalk and marble are the same compound in rather different forms.

P. But chalk, marble, and limestone are surely different!

M. Yes, in their outward appearance. But if I take a small piece of the three substances, and pour hydrochloric acid over them, they behave in the same way;

they froth up and let a gas escape. And the resulting solutions give, in the same way, a white precipitate if I add dilute sulphuric acid. And there are a great number of other reactions which always occur whichever of the three minerals I use. Their difference is only that chalk consists of far smaller particles than the other two, and that limestone contains additional impurities, which make its colour appear grey. But marble also often contains impurities and appears red, sometimes black. So the three are only different physically; chemically they are the same.

P. Are there other compounds of calcium?

M. Innumerable. By pouring water on the burnt lime which is got by strongly heating limestone, it heats itself and swells up, and with more water forms milk of lime, which, mixed with sand, is used as mortar. Gypsum and cement are also compounds of calcium.

P. I'd like to learn more about them too.

M. Again, you must wait till later on for them; otherwise we won't get through our talk. Now we have still the first group—the alkali metals—to consider. Look, in this glass there is sodium.

P. It looks white like silver. But why is the glass sealed?

M. Because sodium combines even at ordinary temperature with the oxygen of the air. As no air can get in through the glass the metal remains unchanged, and its white colour and silver appearance can be recognized. These grey pieces are also sodium.

P. But they look quite different!

M. That is only on the surface, where the compound of oxygen has formed. If I cut off this layer with a knife, the shining metal will be exposed.

P. But it will soon be grey again!

M. Yes, it will combine with the oxygen in the air.

P. What sort of liquid is the piece of sodium in?

M. It is ordinary petroleum. I told you before that it was made of hydrogen and carbon; it contains no oxygen. That is why sodium can be kept in it, and is protected from forming a compound with oxygen.

P. Then can sodium take oxygen out of a compound?

M. Certainly. I throw a piece of sodium into water. It becomes hot, melts, and the ball dances about on the water, always getting smaller. Now take care, a little explosion will follow. See, now it is over, and all the sodium has vanished.

P. Where has it gone?

M. It has united with the oxygen in the water, and has become an oxide, which has dissolved in the water.

P. Is this oxide found in nature?

M. No, it can only be artificially made. But there is another compound that is found in nature. Ordinary salt is a compound of sodium.

P. With what?

M. With chlorine.

P. That can't be true, surely.

M. Why not?

P. Sodium is such an acrid stuff, and chlorine too, and yet their compound makes common salt which we can eat.

M. You have guessed wrong again, as if the elements were contained as such in their compounds. That common salt is a compound of sodium and chlorine tells you no more than that salt can be made with both; and *vice versa*, both elements out of salt.

P. Is that really possible?

M. You shall see it for yourself later on.

P. I can hardly wait to see and learn about all these wonderful things.

M. At present we must speak about the last light metal potassium. Here is a glass tube with potassium.

P. It looks just like sodium.

M. Yes, and behaves in a similar way. If I take a piece out of the oil where it is kept and throw it into water the effect is so strong that a violet flame is the result.

P. Then potassium won't appear as a metal in nature?

M. No! if there had been any to be found, it would have seized all the water to be had, and changed into a compound with oxygen.

P. What are the compounds of potassium?

M. There are a great many. Among the substances that you know I will name saltpetre. Further, potassium is an ingredient of many minerals. Ordinary red felspar contains potassium. There are potassium compounds in the earth from rocks, and they are taken up by plants, which need potassium to enable them to live. For that reason potassium compounds are found on the ashes of plants. They remain behind on burning, as they are not volatile. They can be separated from the ashes with water, and by evaporating the water, are obtained in solid form. The white, salty-looking substance which is so obtained is called potash.

P. I would like to make that.

M. It is quite easy; you only need to stir up wood-ash with water and pour it through a filter (see page 15). Then a clear liquid runs through, which tastes like soap, and leaves a white or grey salt behind, if it is put in a saucer in a warm oven. But take care that you use

only the ash of wood, and not that of coal, because that doesn't contain potash.

P. I have learned so much to-day that I'm afraid I shall never remember it all.

M. All that we have been speaking about will come again later on when we learn the compounds of separate elements. To-day I only showed you that you know quite a lot of chemistry, that is to say, many substances which you have noticed in daily life. You must certainly gain first orderly knowledge of substances and their behaviour, that is, real scientific knowledge.

P. I shan't fail for want of diligence and attention.

15. HEAVY METALS.

M. To-day we begin to talk about heavy metals. Among these are the ones that have been longest known, such as copper, gold, tin, lead, and iron.

P. Why were just these known first?

M. Gold is found as such in the earth. Copper, tin, and lead are very easily separated from their ores, so that it was possible to obtain them at an early epoch without any great experience or skill. Iron came into use much later, as it was more difficult to obtain. But we will make a table again. And here also I will only bring before you the most important metals:

Iron	Nickel	Copper	Silver	Gold
Manganese	Chromium	Lead	Tin	Platinum
Cobalt	Zinc	Mercury		

P. I know almost all of these.

M. You won't know much about manganese. It is a metal that is very like iron, and you have learned

about its compound with oxygen in one of our earlier experiments. It is the substance which we used when preparing oxygen from potassium chlorate to make it come off more easily.

P. Cobalt is blue; is it an element too?

M. No, the blue colour is that of a compound of the element cobalt. Cobalt is also like iron, but keeps better in air, and doesn't rust like iron. You know nickel?

P. Yes.

M. Some coins are made of nickel. Besides, cooking-utensils are made of it. The metal is far whiter than iron, almost like silver, and remains bright in damp air without rusting. It is hard, and is difficult to melt. For that reason it is a fairly valuable metal.

P. What happens to iron when it rusts?

M. It combines with the oxygen of the air and with water. Therefore iron keeps much better in dry air than in damp air.

P. What does nickel-plating mean?

M. It means covering over with nickel. With the help of an electric current the metal can be deposited from solutions of nickel compounds on to any sort of metal object. As nickel keeps so well in air, these covered or nickel-plated objects keep better than without this covering.

P. I don't know chromium at all.

M. I won't tell you much about this element yet. It is whiter than iron, very hard, and melts with great difficulty. Many of its compounds are brightly coloured and so are used as colours for pictures and painting. But you know zinc?

P. Is it the white or light-grey metal of which roof-gutters and whole roofs and bath-tubs are made?

M. Yes; it is much softer and more easily melted than the other metals which were mentioned before.—We now come to the copper group. You already know that metal quite well.

P. Yes, and I know lead too; it is so heavy.

M. Its density is 11.4. It melts very easily, and is soft. Most metals with low melting-points are soft.

P. And *vice versa*?

M. No, it doesn't hold the reverse way. Gold and silver are fairly soft, but have a high melting-point. But it holds again for tin: tin is rather soft.

P. And it can be very easily melted. We did it on New Year's day, and poured it into water. What made the crinkled shapes that we got?

M. You should be able to answer that for yourself. Tin melts at 235° . What will happen if you pour melted tin into water?

P. The water will begin to boil. Now I understand it: the water makes steam, and swells the liquid metal.

M. Right. And it hardens when it comes in contact with the remaining water.—What do you know of mercury?

P. That it is liquid at the ordinary temperature.

M. It is the only metal that has this property. It isn't, however, the only liquid element, for bromine at ordinary temperatures is also liquid.—You know silver too?

P. Yes, from silver coins and teaspoons.

M. Mercury and silver are counted as precious metals, and so are gold and platinum in the next group.

P. Why are they called that? Because they are so expensive?

M. Not exactly for that reason, as there are other much rarer elements, which are much more costly, and yet are not called precious. No, they are called so because they remain bright when heated, and don't become black and ugly like other metals.

P. But why?

M. That you must answer for yourself. I have already told you what happens to iron when it is heated in air.

P. Yes, it combines with oxygen, and the other metals will do the same. Can't the precious metals combine with oxygen?

M. Certainly. Their oxides are also known. But they have the property that when heated they decompose into metal and oxygen. I showed it to you once before with mercury.

P. Oh, so that is why their oxides can't be formed by heating the metal, as they would at once decompose.

M. Right. It requires work to make these metals combine with oxygen, and heat alone can't perform this work.

P. Do the precious metals form no compounds?

M. Yes, some can be obtained if the precious metals are treated with substances which yield work on combination. Sulphur, for example, does so with silver and mercury.

P. Can I see it?

M. Certainly. I put a drop of mercury in a mortar and add some sulphur to it. Then I rub both together. What do you see?

P. It is all becoming black. Now there is a fine black powder, like soot. What is it?

M. It is a compound of sulphur and mercury. In

the same way silver can be combined with sulphur. Rub some sulphur with a cork on a silver coin.

P. The silver is becoming brown and blackish grey.

M. There again is another combination of both elements. Both metals unite directly in the same way with chlorine, bromine, and iodine.

P. Aren't these precious, then?

M. No. But gold and platinum are still more precious, as they don't combine with sulphur by rubbing them together.

P. Don't they combine with anything?

M. Yes, they can combine with chlorine. But this compound decomposes into elements again on heating, just as you saw with mercuric oxide. We will stop with that for to-day.

P. Chemistry is a tremendously large subject.

16. MORE ABOUT OXYGEN.

M. To-day we will learn more about oxygen.

P. I know about it already.

M. Only very superficially, for you know only a very small part of what is known about it. And what I am going to tell you is only a little part of what is known.

P. But you know all about it?

M. No, I don't think there is a single man who really knows all that is known about oxygen.

P. I don't understand that. If no one knows it, then it isn't known.

M. One man knows one part, another man knows another, so that the knowledge is present in somebody's

mind, but not all in the same person's. Besides, almost all is to be found in books, and is accessible for every one who wishes. From time to time a man is found who discovers as much as possible about it, and puts it all together in a particular book, to save others the trouble of searching. But he can only give extracts, and so one who for some reason wishes to learn exactly what is known of the subject must look over the books himself, or by experiment arrive at the desired knowledge.

P. Is everything right that is found in books?

M. Most of it; and when there is anything wrong, it is no intentional error, but the author for some reason made a mistake. A most remarkable and praiseworthy thing in scientific literature is that almost every word is written conscientiously.

P. But if someone has made an oversight and written something wrong, the error would remain there forever.

M. Only until it is contradicted by some other fact that is found. Then it is seen on which side the fault lies, and after that one can generally find out how the error came. But now we will go back to oxygen. You remember how we made it before?

P. Yes, from a white salt. What is it called?

M. Potassium chlorate. It contains about two fifths of its weight of oxygen, which it gives up when gently heated, especially if a little oxide of iron or of manganese be added.

P. You told me that already (page 114) but it strikes me as so remarkable that I should like to see it. Can you show me how iron oxide makes it easier for the oxygen to come off?

M. Certainly. I am melting a little potassium chlorate in a test-tube. What do you see?

P. It melts; now it has become as clear as water; now quite small bubbles are rising.

M. These are traces of oxygen. Now I take the lamp away from the glass, and add a little oxide of iron to it.

P. It froths like soda-water. Does the salt begin to boil?

M. No, oxygen comes off suddenly. If I put in a burning splinter, it catches fire. You know that is the test for oxygen. You see that even though the salt has cooled a little on taking away the flame, the oxygen comes off much more quickly on adding the oxide of iron.

P. That is really very curious. Why does it happen?

M. The oxide of iron has acted like oil on a rusty machine, or like a whip on a horse.

P. I don't understand that.

M. You are not the only one. It is a fact that many chemical processes which go very slowly of themselves can be accelerated by adding other substances to them, even though the added substances undergo no permanent change. The investigation of the question why these accelerations, which are ascribed to *catalytic* action, really take place is a difficult scientific problem, and perhaps in a few years I may be able to give you an answer. In the mean time we will use this fact as a convenient help.

P. When I know more I'll try to find out the reason of catalytic actions.

M. That is a good plan. But now we will make some oxygen. You know already how it is done. First I will place this flask filled with water here, for we must first expel the air from the flask by oxygen before I collect it.

P. But you will lose some oxygen in that way.

M. That doesn't matter; if we want it pure, we must make up our mind to that. You will always meet with that same difficulty in future. Now I begin to heat, and you see that soon bubbles rise out of the glass tube. Now place the flask on the stand, but take care that you always keep its mouth under water or else air will enter.

P. How quickly it's going!

M. Yes; it will be better to take the flame away for an instant. Now fill an empty flask with water and have it ready.

P. But how can I turn it upside down without letting the water run out?

M. Hold your thumb on the mouth.

P. My thumb is too small.

M. Then take your hand or a piece of cardboard, or anything flat. The best thing is a cork that fits it.

P. Now the first flask is full of oxygen.

M. I close it under water with a cork, and can take it out and put it aside.

P. Why do you put it upside down?

M. Because generally the cork doesn't fit tight, and the water then prevents the oxygen from coming out. Now the second flask is nearly full; get another flask ready.

P. I didn't think that so much oxygen could come out of so small a quantity of salt; the sixth large flask is half full, but it has stopped coming now.

M. Yes. Now we will take the tube out of the water; if we didn't, the water would rise up into the flask and break the hot glass.

P. What a lot of things there are to think about!

M. Yes, the art of experimenting is not to require

to think about such things, but to do them involuntarily. Now we will do what we had to put off before; we will calculate the density of oxygen.

P. Calculate? But we must first measure it.

M. The measurements are already made. I used 10 grams of potassium chlorate; it contains about 4 grams of oxygen; more correctly 3.9. Our flasks are each half a litre or 500 cubic centimetres in capacity, as you can see by the 500-mark which is stamped upon the bottom of each. We have thus collected somewhat less than 3 litres of oxygen, so each litre weighs in round numbers 1.3 grams, and each cubic centimetre 0.0013 gram, so (see page 48) the density of oxygen is equal to 0.0013.

P. I shouldn't have thought the calculation could have been made so easily.

M. It was easily made, but it was not exact. I wanted to show you how to arrive at a knowledge of such values. It wasn't my intention to make an accurate measurement.

P. One thing more. You said that the weight of the oxygen from 10 grams of potassium chlorate was 3.9 grams, but not how you found it out.

M. That's not difficult. You weigh the test-tube with the chlorate before heating, and then afterwards.

P. I see it now. The loss of weight is equal to the weight of the oxygen that has come off.

M. Yes. Here you have an application of the law of the conservation of weight.

P. So I have used a law of nature without knowing it. What is the use of stating these laws of nature when you use them without knowing them?

M. It was an accident that you used it rightly. It is just as easy to make a wrong use of them, and in order

to avoid that the law must be expressed and used intentionally. This is troublesome at first, but later on, if my teaching makes the right impression on you, whenever you learn anything new, you will find it necessary to state it as a law of nature.

P. I don't think I shall ever get as far as that.

M. We mustn't forget that we are speaking of oxygen all the time. When we collected it over water, did you notice anything strange?

P. I don't think I did.

M. The bubbles of oxygen rose through the water without diminishing in size. That is a proof that oxygen is insoluble, or very sparingly soluble in water.

P. Can gases dissolve in water, then?

M. Certainly. You have an example in soda-water. As long as it is in the bottle it looks quite clear, but when you pour it out a quantity of gas escapes which was dissolved before.

P. Yes, I have seen that. But why does the gas escape when you pour it out?

M. Gases dissolve in water and other liquids more readily at high than at low pressures. In the bottle the solution is at pretty strong pressure, and when the bottle is opened the pressure is relieved, so that the gas escapes.

P. Ah, that is the reason why it pops and foams. What sort of gas is it?

M. It is carbonic acid gas, the same gas which is produced when carbon burns in air or oxygen. We shall get to know more about it afterwards.

P. Then we ought to be able to make carbonic acid gas out of smoke.

M. That doesn't work; for in smoke the gas is mixed

with much nitrogen of the air, and besides, it contains disagreeably-smelling stuff from the coal.

P. I only meant it as a joke.

M. But the proposal is quite a sensible one. If carbonic acid gas were an expensive gas, it would be worth considering whether it couldn't be separated from the mixture and purified. But because such a separation costs trouble and money, the question is asked, can it not be made in a cheaper way? The answer to that question is the foundation of the chief part of chemical industry. But we will go back to oxygen. It is very sparingly soluble in water; while water dissolves its own volume of carbonic acid gas, it dissolves only about a fiftieth of its own volume of oxygen.

P. But if it is more strongly compressed?

M. It remains the same. If a gas is compressed more strongly, more goes into the same volume, and water dissolves exactly as much more. On the other hand, the proportion varies with the temperature; the higher the temperature the less gas dissolves. What do you notice when fresh spring-water is allowed to stand in a room for some time?

P. Do you mean the little bubbles of air that stick to the side of the glass?

M. Yes, that is what I mean. When the cold water which is saturated with gas warms up, part of it must escape, and it does so in the form of bubbles, which gradually grow larger, and finally separate and rise. We have learnt something about the behaviour of oxygen when it is kept in a flask by itself, and when it is brought together with other bodies. Now we will get to know about it in the free state.

P. I am curious to hear about that.

M. You know that it is a constituent of air, and indeed the most active. The other constituent is called nitrogen, and animal life cannot survive in it, nor can flames burn in it, but go out. As air penetrates everywhere, so oxygen can penetrate everywhere, and it combines with substances which are present; that has happened as long as our earth has been in the same condition as it is now; that is, for thousands and thousands of years. The consequence is, that everywhere on the earth's surface compounds of oxygen are to be found. Most of the substances which we know contain oxygen. Compounds of other elements with oxygen are called oxides. The word oxygen comes from the Greek and means an acid substance.

P. What has it to do with acid? It isn't acid, surely?

M. It occurs in many acid substances. It was formerly believed that its presence was necessary to the existence of acid substances, but that has subsequently been found to be erroneous.

P. Why did they keep the false name?

M. Nobody thinks about it now, so it doesn't matter. But we will leave the name and go back to the thing. You know that by burning fuel we not only warm our houses in winter, but we drive our machines, lift weights, in fact, do all sorts of work that we require to do. Burning means union with oxygen. How does it happen that that enables us to do work?

P. Oh, I know that from our former lesson. Burning is a chemical process by which energy is set free.

M. I am glad you remembered it. Now I will give you a riddle. How does it happen that the coal doesn't burn in our cellar?

P. Because there is nothing there to set it on fire.

M. How can things be set on fire?

P. You put other burning stuff beside the coal till it begins to burn.

M. That is not a sufficient answer. What happens to the coal when you put burning stuffs beside it?

P. Now I've got it. The coal gets warm, and so catches fire.

M. That is right. So hot coal can unite with oxygen and cold coal can't. And that is the reason why coal burns in the fire, and not in the cellar. But now I will tell you something. It happens not infrequently that coal which is left lying in large heaps catches fire of its own accord and burns without anybody's having lighted it. Such a heap gets hotter and hotter, and when it is not cooled by spreading it out, it begins to burn.

P. I can't understand why. Where does the heat come from?

M. That is a sensible question. It comes from the burning of the coal.

P. But that only occurs later on.

M. No, the coal is always burning. Only this happens so slowly at low temperatures that the temperature rises very slightly, and so you can neither see it smoke nor catch fire. When large heaps of coal, however, lie together, so as to prevent heat from escaping, the temperature rises; then the burning takes place more quickly and the temperature rises higher, and finally rises so high that the coal begins to glow and bursts into flame.

P. I can't imagine coal actually burning in the cellar.

M. I will remind you of something else. Do you remember what became of that log that was lying out in the yard?

P. It is just the same as it was.

M. No, that is not exactly true. If wood lies for a long time it decays. Do you know what that means?

P. The wood gets rotten and light.

M. Yes, and it gets smaller and smaller and finally disappears.

P. What has become of it?

M. It has been burnt too. When oxygen is kept away from wood, it doesn't alter like that.

P. But how can you call it burning when you can't see a flame?

M. Burning in the chemical sense of the word is combination with oxygen, whether a flame is visible or not. For whether a flame or glowing appears depends upon the temperature rising high enough, at least to 500° ; below that substances don't glow, because they send out no light. Whether the temperature rises so high doesn't depend upon the chemical change, but on whether the heat is sufficiently kept in.

P. Are there many combustions without light and heat?

M. Plenty. But without evolution of heat, such "flameless combustions" don't take place. Just as much heat is evolved as if combustion had taken place with a flame. When a chemical change takes place, the amount of heat evolved depends on the beginning and the end; it doesn't matter if it takes a long or a short time.

P. But when the coal on the fire burns brightly, surely it gets hotter?

M. The amount of heat which a definite quantity of coal gives out is always the same. But of course if you burn more coal in the same time, the fire will be hotter.

P. I really don't quite understand that.

M. The fire gains heat by the burning of the coal on the one hand, but on the other hand it loses it by heating the room. It is something like pouring water into a bucket with a hole at the bottom. The quicker the water runs in the higher it will stand in the bucket. But that has nothing to do with the total quantity of water that you pour into the bucket.

P. Yes, now I understand. When a tree decays, it is like water running so slowly into the bucket that it's never visible. But how can it be found out that as much heat escapes as when ordinary burning takes place?

M. That is deduced from the law, that energy neither disappears nor is created. That has been proved and confirmed in innumerable cases, and it can be taken for granted in cases where it has not yet been proved.

P. But it's surely possible that it may prove to be false in some one case.

M. Certainly. But then other things would show it was wrong, and the error would soon be discovered. What do you know about the relations of animals to air?

P. They can't live without air, so I always make holes in the lid of the box in which I keep my silkworms.

M. But there is air in the box anyhow, along with the silkworms, so what is the use of the hole?

P. But the animals require fresh air.

M. Why?

P. I was taught that. People require fresh air if they are to keep healthy.

M. Quite right. The important point is that both animals and men shall get enough oxygen. Breathing consists in pumping oxygen into the lungs, where it is taken up by the blood and led through all parts of the body.

P. What's the good of that?

M. To burn the body.

P. You're surely in fun?

M. No, I'm really in earnest. The process of the body is exactly the same as with the coal in the cellar and the decaying wood. Certain substances in the body combine with oxygen, although not so quickly as with burning wood.

P. Is that what makes the body warm?

M. Certainly. A dead man no longer breathes, so his body gets cold. But that is not the only effect produced. The body does all sorts of work, which must be produced from something, because work can't be made of nothing. This work or energy is produced from its combustion.

P. Then surely both our bodies ought to have burnt up long ago?

M. Quite right. If we were not always introducing new combustible matter. That happens when we take in food.

P. Then I ought to be able to eat wood and coal.

M. Yes, if you could only digest them; that is, if your stomach was able to change them into soluble compounds, which would be carried with the juices of the body to all the parts, where they could combine with oxygen. For that matter, cows can digest wood if it is given them sufficiently fine. The substances of which grass and hay are made are not very different from wood.

P. Does the food burn in the lungs?

M. You mean because air enters the lungs in breathing? No, oxygen of the air is taken up by the blood in the lungs and passes through the arteries into all the tissues of the body; and there it meets the dissolved

foods and burns them up. Besides, food has another use: it replaces the used-up parts of the body. If you think of your body as a steam-engine, food is not merely the coal which makes it go, but also the metal with which it is repaired.

P. Is that the case with all animals, or only with warm-blooded ones?

M. You think that cold-blooded animals don't require it because they are not warm? That isn't right, because they are all a little warmer than their surroundings, and they all breathe. All animals require food and oxygen because, besides keeping themselves warm, they have to do work. They move about.

P. But plants don't move. What about them?

M. With plants there is a different state of affairs which you can't quite understand yet. We will come back to them, and then you will see these things in a connected manner.

P. It has been a jolly lesson to-day.

17. HYDROGEN.

M. We will talk about hydrogen to-day. What do you know about it?

P. It comes in water.

M. That is not expressed well; because it can be obtained from water, hydrogen is an ingredient of water. What other ingredient has water besides that?

P. I think you said oxygen.

M. Right. Water consists of hydrogen and oxygen; that is to say, water can be formed from both these elements, and in the same way both these elements can

be obtained from water. How do you think oxygen could be made from water?

P. I don't quite know. Perhaps water could be heated and it might decompose into the two elements, just as oxide of mercury decomposes into its ingredients.

M. That is quite a good suggestion. But you already know what comes when water is heated.

P. Yes, steam.

M. Right. Steam is only water in another form.

P. Perhaps it requires greater heat.

M. You have hit upon the right thing; if steam is very strongly heated, it really decomposes into oxygen and hydrogen. But when the mixture is cooled, it combines again "to form" water, and one can only tell by a special artifice that it has been decomposed. Besides, only a mixture of oxygen and hydrogen would be obtained, and as both elements are gases, it would not be easy to separate such a mixture.

P. Then a way must be found out to hold fast the oxygen somehow. Can't it be made liquid, like the mercury in the decomposition of mercuric oxide?

M. Yes: to do that the gas mixture must be cooled below -180°C . That is too inconvenient a way. I will show you another: we do not separate the oxygen alone, but as a compound with some other element, and arrange it so that the compound is not volatile.

P. I don't quite understand.

M. I will tell you. We pass steam over glowing iron. You know that iron combines easily with oxygen.

P. Yes, it burns with a lovely rain of sparks.

M. Now the iron acts on the steam in such a way that it takes the oxygen and combines to form iron

oxide; the hydrogen then remains over. Iron oxide is a solid substance even at a red heat, and therefore remains where the iron was; but hydrogen is a gas, and passes further along; it can then be collected over water in the same way as oxygen.

P. That still seems very strange to me.

M. I will give you a simile. Oxygen is a bone which the cat hydrogen had to start with. Then the dog iron comes along and takes the bone from the cat, and the cat hydrogen must run away without the bone.

P. Then iron is stronger than hydrogen, and so takes the oxygen away.

M. The old chemists made the thing out to be something like that, and for the present you may rest content with that simile. Later on, when you know more about chemistry, you shall have more definite examples.

P. May I see the experiment?

M. It is not quite simple to arrange, for a fairly strong heat is required. The best way is to fill a piece of hard glass tubing with a bundle of iron gauze, to heat the middle till it glows, and lead the steam over it from a flask in which water is boiling at the other end of the tube; a glass tube is attached, which is allowed to discharge into an inverted flask under water. Then, exactly the same as with oxygen, the gas-bubbles rise and collect in the flask.

P. What a shame I can't see it!

M. I will show you another experiment instead, with which you can see much the same kind of thing. You remember that salt contains a metallic element which is called sodium. Here is some of this metal. I have already shown you (page 111) that it combines rapidly with oxygen, and that it can also take it out of water.—

Now I take a little piece of sodium the size of a pea, wrap it up in a piece of filter-paper, and stick it with a pair of tongs under the inverted tube, which stands in the water (Fig. 23).

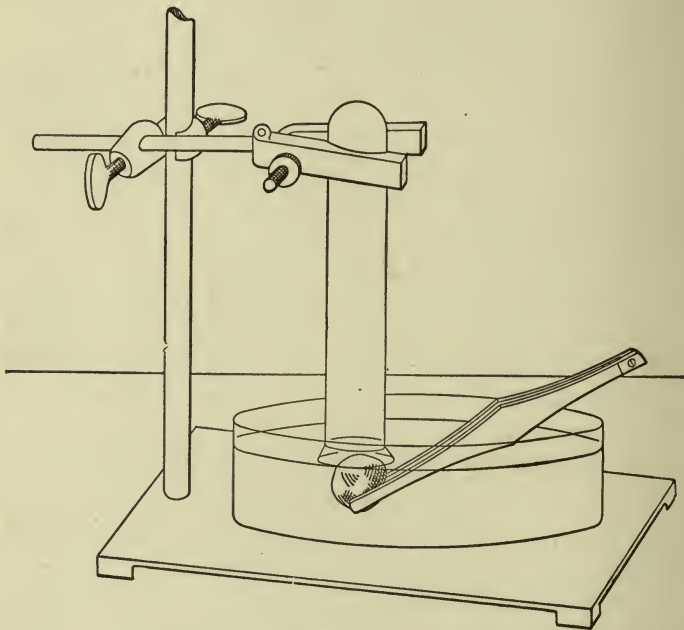


FIG 23.

P. The sodium is slipping out of the paper! Now it seems to be boiling, and some air has collected in the tube.

M. Sodium acts in the same way as I told you iron did, only at ordinary temperature and much more quickly. It takes the oxygen of the water and sets free the hydrogen.

P. But why did you wrap it up in paper?

M. Without doing that it would have been difficult to put it under the tube, as it would have sprung out of the tongs. It gets heated and melts. As we haven't obtained a great deal of hydrogen, I will repeat the experiment and you can see that sodium glides about on the top of the water like a liquid ball.

P. Why didn't you take more sodium at once?

M. Because the experiment is not quite without danger if large quantities are taken. There are often impurities in the sodium which make it explode, so that only small quantities must be taken in order that an explosion may not be dangerous. Remember this when you make the experiment alone.

P. Yes, but tell me what has become of the compound of sodium and oxygen which must have been formed?

M. A very good question! Well, as it is neither on the top of the water nor under the water, where can it be?

P. In the water? But the water is still quite clear.

M. Quite right. So what properties must the compound have? Think of our first talks about sugar and copper sulphate.

P. I know! It has dissolved.

M. Quite right. Taste the water so as to convince yourself.

P. Horrid, like soap!

M. You have discovered one reaction of the compound which is formed. But we will speak of that later. Let us pay attention to hydrogen at present. What does it look like?

P. Like air.

M. Yes, hydrogen is a colourless gas. Now I take the tube out of the water, closing the mouth with my

thumb, and take away my thumb when I bring it near a flame. What do you see?

P. The hydrogen appears to burn; but the flame is very pale.

M. Quite right. Hydrogen is a combustible gas. But in order to learn more about its properties we should have to put sodium again under the mouth of the tube, and that would be tiresome. I will rather show you another method of making hydrogen, by which it is much easier to produce large quantities. For this purpose we take other compounds of hydrogen which give it up more readily than water does. Such a compound is hydrochloric acid; as its name implies it consists of hydrogen and chlorine.

P. Is that the same chlorine that is contained in common salt?

M. Certainly; there is only one kind of chlorine. Here is a solution of hydrochloric acid in water, as it is sold by the druggists.

P. It looks just like water.

M. Yet it is not water. I pour some drops into a wine-glass, and fill it half full of water; taste it.

P. Will it have as bad a taste as the last?

M. No, quite different.

P. Yes, it tastes sour. But not very pleasant, and it makes my teeth rough.

M. Yes, because it tastes acid it is called an acid.

P. Why did you pour in so much water?

M. Because strong hydrochloric acid is poisonous, though dilute acid isn't. The reason your teeth felt rough was that the acid attacks the substance of which the teeth are made. But now we will begin our experiment. I have here, in a flask, clippings of sheet zinc. Now we ll

put into the flask a cork provided with two holes. Through one passes a tube with a funnel at the top, and it reaches to the bottom of the flask; and through the other a short bent glass tube to which I connect my delivery-tube with a piece of rubber tubing—the one I used before for oxygen (Fig. 24). Now I pour hydro-

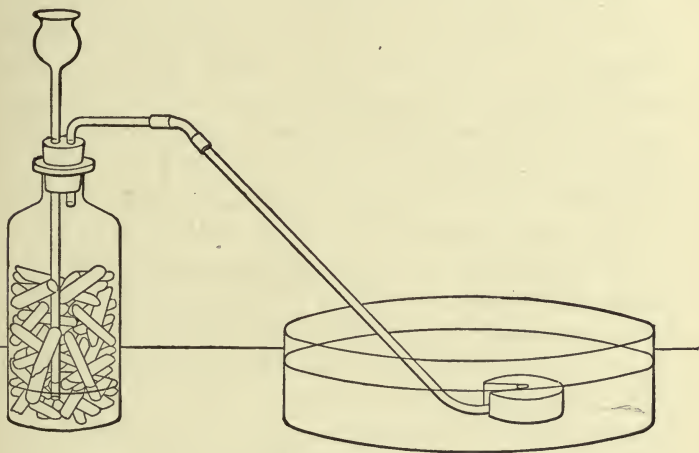


FIG. 24.

chloric acid through the funnel, and at once you see gas coming off.

P. Quick! Place the flask over it to catch it.

M. No, I will first collect some gas in a test-tube. Stop, here is the first one full. I lift it out and hold it to the flame. What happens?

P. Nothing. It must have been the air that was in the flask.

M. Quite right. Now I repeat the experiment.

P. That gave a loud crack.

M. I will collect some more samples. You see, the

first ones explode, but now the gas burns quite quietly, like the hydrogen we made by using sodium. Now we can collect it in flasks, and when the evolution of gas slackens, we only need to add a little more hydrochloric acid and it begins again.

P. Please explain all this to me.

M. With pleasure: First the production of hydrogen from hydrochloric acid and zinc; that is just like the formation of hydrogen from water and iron. The chlorine takes the zinc rather than stay with the hydrogen, and so the hydrogen is set free. It is very convenient that this takes place at the ordinary temperature, and without the necessity of using a dangerous metal like sodium.

P. I understand that. But what made it pop?

M. Look, here I have a test-tube that is only half filled with water. I close it with my thumb and place its mouth under water. Now the tube is half full of air. I displace the water from the other half of the tube with hydrogen, which is not explosive. If I bring this tube with a mixture of hydrogen and air near the flame—

P. By jove! what a thundering crack!

M. You see that a mixture of air and hydrogen explodes, though pure hydrogen doesn't. If I were to light such a mixture in a flask, it would burst, and the pieces might cause serious injury. Now, as there was air originally in the bottle, it would have made a dangerous mixture; and it was only after the air had been driven out by hydrogen that pure hydrogen escaped. Remember that you must always test the gas when you make hydrogen in this way, and not collect the gas before it burns quietly.

P. So the explosion is a test for air in the hydrogen? But why did it pop?

M. Because the hydrogen was completely mixed with

the oxygen, which it required for burning, and the flame, when it once starts, spreads immediately through the whole mass. But when pure hydrogen burns in the air, combination can take place only when the two gases touch. The shape of the surface when this takes place is the same as that of the flame. Can you tell me why a quietly burning flame like that of a candle has a conical shape?

P. Let me think. Yes, the burning gas rises and burns, and because it grows less the flame gets narrower.

M. Quite right. Now let us go back to hydrogen. I fill two tubes with it, and leave one with its mouth up and the other with its mouth down. Which will the hydrogen stay in?

P. When you ask questions, I am afraid of some catch, and am likely to answer wrongly. So I'll say the opposite of what I think. The hydrogen will stay in the tube with the mouth downwards.

M. Let us try. First I bring into the flame the tube which has its mouth upwards, and try to set its contents on fire; nothing happens, and when I hold a burning match in it, it goes on burning; and so the tube contains air. Now the other tube. I hold its mouth above the flame—

P. I was right after all. The hydrogen stayed in it. It burns with a pop. That is most astonishing.

M. Now think. What did I tell you about the density of hydrogen?

P. That it was the lightest of all substances. But still it has some weight and ought to fall. Oh, now I know. It is lighter than air, and so it floats up in the air like a cork in water. But in an empty space it ought to fall.

M. So it would if it were a solid or liquid. But a

gas spreads all through an empty space till it fills it equally throughout. Now do you understand the experiment?

P. Yes; the hydrogen tries to rise in the air, and if it can find an opening above, it escapes; but if the opening is below it, it must stay there.

M. Quite right. Now you deserve a treat, and I will show you a pretty experiment which will illustrate its behaviour even better. I have made some soap-suds. Now, by means of a piece of rubber, I pin to the gas delivery-tube a piece of glass tubing stopped loosely with cotton-wool, and plunge the end below the soap-suds.

P. You can really blow soap-bubbles with hydrogen?

M. Yes, and here is a very big one; it separates from the soap-suds, and rises like a balloon.

P. Oh, how jolly! But what is the use of the cotton-wool in the tube?

M. The hydrogen carries innumerable little drops of acid with it as a sort of mist, and when these touch the soap-bubble, it bursts. But the little drops stick in the cotton-wool and don't get into the bubble.

P. Are the big balloons that are sold in shops filled with hydrogen?

M. Yes.

P. I used to have one, and the first day it went up all right, on the second it would hardly rise, and the third day it wouldn't rise at all. Did the hydrogen grow heavier?

M. No, but hydrogen is such a fine-grained stuff that it can't be kept in by a thin sheet of india-rubber; it passes out, and some air enters instead.

P. Oh yes, I remember my balloon got much smaller.

I thought at first that the mouth hadn't been tightly enough tied, but it was.

M. Quite right. You see you shouldn't keep hydrogen in any kind of vessel for a very long time; it generally gets out and air enters, making an explosive mixture.

18. OXYGEN AND HYDROGEN.

M. What did you learn yesterday about hydrogen?

P. That it can be made from its compounds by taking away by means of another substance what it is combined with. It can be set free from water, in which it is combined with oxygen, by iron or sodium.

M. And how do the two metals differ in doing it?

P. Iron does it only when glowing, sodium does it at the ordinary temperature.

M. And further?

P. You can take hydrochloric acid and zinc. The zinc takes the chlorine, and the hydrogen comes out.

M. What properties has hydrogen?

P. It looks colourless, like air, but it weighs much less. But you never told me how much lighter it was than air.

M. Its density is about 14 times less than that of air. One litre of hydrogen, like what we have in the flask, weighs less than $\frac{1}{11}$ gram. What more do you know about hydrogen?

P. It burns in air, and if it is first mixed with air, it gives a loud bang, because the whole mass burns suddenly.

M. Quite right. What is made from hydrogen when it burns?

P. You never told me.

M. You ought to have been able to discover it for yourself. Just think a minute. What happens on burning?

P. The substances combine with the oxygen of the air.

M. Right. Now if hydrogen combines with oxygen, what is made? Don't you remember that we have just been speaking about such a compound; which was it?

P. You told me about water. Should water be made?

M. Certainly, water is made. We soon see it. Don't you remember how I showed you the formation of water with a burning candle?

P. Yes, with a large beaker that was held over it. It became covered with drops of water.

M. We can do that, too, with a hydrogen flame. I fasten, to the apparatus, a glass tube the end of which I have made narrower, and let the hydrogen burn from it (Fig. 25). There, you see the drops at once.

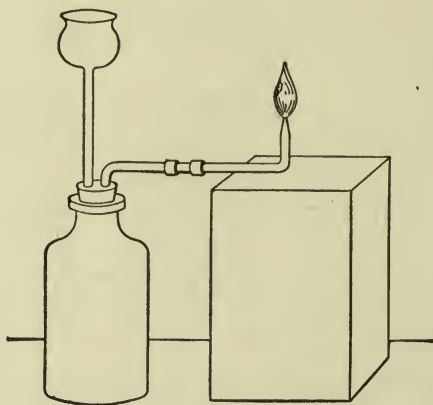


FIG. 25.

P. How do you make a point like that?

M. You hold the tube in the flame, turning it till the place is quite soft, then you pull it apart lengthways, and cut through the narrow part with the glass-cutter.

P. Please let me do it. Now the tube is soft, and now I pull it. Oh, it is as thin as a hair!

M. You pulled too hard and too quickly. Besides, this thin hair is also a tube, as glass doesn't fall together with pulling.

P. Really? I can hardly believe that there can be such a thin tube.

M. Break a piece off and put the end in the ink and

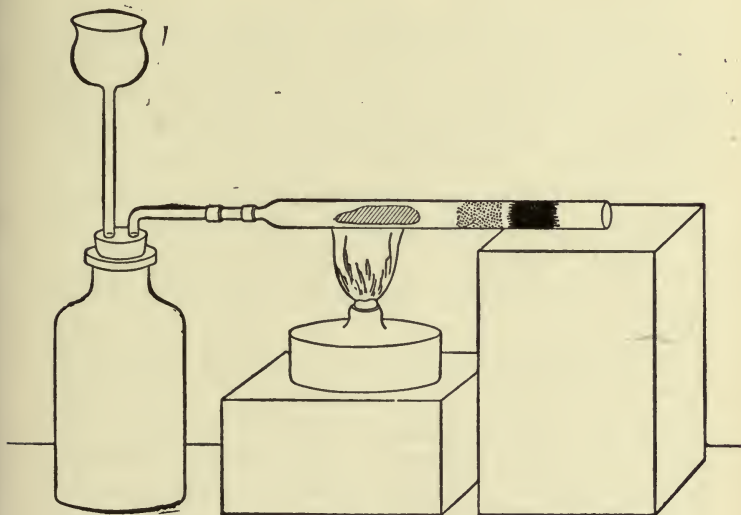


FIG. 26.

then you can see how the black liquid comes through. But we must return to our hydrogen. Hydrogen can combine not only with free oxygen, but can take oxygen from other compounds. Do you remember mercuric oxide? What sort of substance was that?

P. A red powder; a compound of mercury and oxygen.

M. Yes. I take a little mercuric oxide, put it in a

glass tube which I attach to the hydrogen apparatus, let the hydrogen pass over it, and heat it carefully (Fig. 26).

P. Mercury separates again.

M. Right, but further?

P. There are clear drops that look like water; is it water?

M. Yes. This time the hydrogen has taken away the oxygen from the mercuric oxide to form water, and the mercury is set free.

P. Does that happen with all oxygen compounds?

M. Not with all, but with a great many. Most oxides of the heavy metals can be thus changed into metals. This change is called reduction, the opposite of oxidation. The changing of a metal into its oxide is called oxidation, the changing of an oxide to the metal, a reduction. As hydrogen makes this change possible it is called a reducing agent. Notice this name.

P. I have learned a great deal that I didn't know before.

M. I will make it easier for you by showing you some more experiments. This black powder is called copper oxide. It is easily formed if copper is heated for some time in the air. I put some of it in a tube, pass hydrogen over it, and heat it again; do you see what the copper looks like?

P. Yes, the powder is getting red like copper, and again drops of water are falling in the tube.

M. I take away the flame and let it get cold, while the hydrogen is going through. Now I can shake out the red grains, and if I rub them in the mortar you will see they will shine like metal.

P. How pretty! Why do they only shine after they are rubbed?

M. The copper was not even and smooth before.

As the oxygen has separated from the copper oxide, the copper remains behind like a sponge.—This yellow powder is called oxide of lead and is a compound—

P. Of lead and oxygen.

M. That is a good answer. I'll allow you to reduce it yourself for that. Do it in the same way as before.

P. Bright drops like mercury have appeared; is that lead?

M. Yes; as lead melts very easily, it is obtained at once in a liquid form. Pour these drops onto a piece of paper and then you can see how they solidify into a soft and unelastic metal which is easily bent. Those are the properties of lead. But now we are going to do a special experiment. This is the iron oxide which we obtained before by burning iron powder in the air. We are going to reduce this by means of hydrogen.

P. How can that happen? You told me yourself yesterday that iron is stronger than hydrogen, because it takes the oxygen out of water and drives away hydrogen. So how can hydrogen become stronger than iron?

M. One must make experiments even when one thinks they won't come to anything. For every conclusion we draw may be erroneous, and must be tested by experiment.

P. I am really curious about it. Do you see, nothing is happening; the broken bits only become a little blacker.

M. Just notice carefully the further part of the tube.

P. H'm! There really appear to be drops of water coming there. On the one hand, it looks as if nothing were happening, and on the other hand, as if something were happening after all.

M. I will let it cool again while the hydrogen is still

passing over it. Now just rub the black mass in the mortar, as we did with copper.

P. It is becoming bright too.

M. Then it is metallic iron.

P. Now please tell me how it is possible that there can be such a contradiction. I thought that laws of nature always held.

M. What law of nature has changed here?

P. One force cannot well be greater and smaller than the other. First iron was stronger than hydrogen, and afterwards hydrogen was stronger than iron. That is surely a contradiction.

M. The contradiction only lies in this, that you look upon the reason of chemical change as a mechanical force; a force like this doesn't let itself be known or measured beforehand.

P. What is it, then?

M. If I were to answer this question, you wouldn't understand me. You must know many facts about chemistry before you can think of connecting them by a theory.

P. But can't you say something that would put me on the right track?

M. Yes; out of your own wrong example; one man can carry a certain amount of water; but if much more water comes it will carry the man away.

P. So you mean that in chemical changes it depends on which substance is present in the greatest quantity.

M. Something like that. But we must go back to our hydrogen. You know now that in the combining of hydrogen with oxygen water is formed, and that for this purpose oxygen can be taken out of other compounds. But there is still something else that happens: I set my

hydrogen apparatus going again, and after the mixed gas has gone, light the hydrogen. You see that the flame is fairly pale.

P. At first it is always bluish, but afterwards it becomes lighter, and looks yellow.

M. That is because the glass tube from which the hydrogen burns becomes hot. The element sodium is contained in glass, as you already know. A little evaporates from the hot glass, and this vapour colours the flame yellow.

P. How is that?

M. Glowing sodium sends out a yellow light, just as, for example, the metal copper reflects red light. The yellow colouring of the flame is a test for sodium; it is always to be found when sodium is present, and is absent when there is none there.

P. But nearly all flames are yellow.

M. In nearly all burning materials sodium is present, and a very little is enough to make the yellow colour. But we can make a pure-coloured hydrogen flame. I have here a little piece of platinum-foil; I make it soft by heating, and then wrap it firmly round a knitting-needle; so I get a very serviceable little tube of platinum. I put a few millimetres of this in

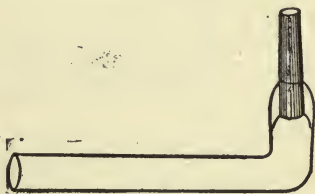


FIG. 27.

a glass tube which is slightly wider than it, and heat the place. You see how the glass tube lies round the platinum? Now it is melted and closed up all round, and I have a burner-tube with a platinum tip which I can afterwards bend to a right angle. (Fig. 27.)

P. Why platinum?

M. Because this metal is only melted with great difficulty and is not easily attacked. When I attach the tube to the hydrogen apparatus, I can leave the gas burning for hours, and the flame will never become yellow. Now I hold a morsel of platinum wire in the hydrogen flame. What do you see?

P. The wire shines very brightly; the flame seems to be very hot, then.

M. Quite right. A glowing body glows more brightly the hotter it is. With gases this is not the case: glowing hydrogen vapour gives very little light; that is why the hydrogen flame is so faint, while it makes every solid body that it reaches glow so brightly.

P. Every one?

M. Every one that doesn't melt or turn to vapour. Here I have a fragment of incandescent mantle. Just look how brightly it glows. And iron wire begins to glow brightly at first too, but it soon melts and burns. Very well, then, tell me what is formed in the flame besides water?

P. Heat.

M. Right. What is heat? Remember what we spoke about a short time ago, when we were talking about combustion.

P. Yes, you had a special name for it: I think energy.

M. Quite right. What is energy?

P. Everything that comes from work and can be changed into work. How can you get work from burning hydrogen?

M. Now you heard for yourself what a loud bang a mixture of hydrogen and air made, and I told you also that it could break glass. Work is used up for that.

P. A funny sort of work. Mother would very soon put a stop to it if I wanted to break her glasses and said I was at work.

M. It is work all the same, as it requires a certain amount of exertion. To be sure, it is not useful work. But when the miller grinds his corn, his mill does similar work, and that is useful.

P. Can any useful work be done with the explosive gas?

M. Certainly. There is a certain sort of machine in which an explosive mixture of air and coal-gas is burnt. The explosion drives a piston forward, and as the machine turns further, gas and air are again sucked in to form the explosive mixture, and this is again exploded, so that the piston each time receives a powerful push. Such gas-engines are now made of the largest dimensions, and in many respects are much better than steam-engines.

P. Are engines of motors made like that? They puff in the same way.

M. They are something like, only with them the explosive gas is made with benzine vapour.

P. Then explosive gas can be made with all sorts of things?

M. If a combustible gas or vapour is mixed with as much air or oxygen as is necessary to burn them up, an explosive gas is always obtained. For then the flame can always go through the whole mass and burn it at once, whereas otherwise the burning can only take place where the air "reaches."

P. Yes, you made that clear before.

M. I made something else clear to you too. How can the hydrogen flame be made still hotter than it is at

present? Do you remember what I told you about burning in air and in pure oxygen?

P. Yes, I know: if you were to burn hydrogen with pure oxygen, the nitrogen in the air wouldn't need to be heated with it and the flame would be hotter.

M. Right. How would you do that?

P. I would let the hydrogen flame burn in a flask which contained oxygen.

M. Quite right, but not convenient. A very high temperature is obtained if oxygen is blown into the hydrogen flame.

P. But how can that be done?

M. Well, we could take an empty india-rubber balloon and fill it with oxygen and then press it; then the oxygen would stream out of the opening. But I will show you how a proper gasometer is made. I have here two very large flasks which are provided with corks, in each of which are two holes. Through one hole a siphon of glass goes to the bottom, through the other, a short bent tube (Fig. 28). Both siphons are connected by a piece of rubber tubing, and one flask is filled with water.

P. I can't quite see what use all this is going to be.

M. Just notice: I now connect an oxygen apparatus (page 84) to the bent tube of the flask filled with water, and place the other flask at a lower level. If I make oxygen by heating, it goes into the upper flask and the water runs through the india-rubber tube into the lower one.

P. That is pretty.

M. So now the higher flask is full of oxygen. I take the oxygen apparatus off, and close the rubber tube with a clip.

P. What is a clip?

M. It is a wire spring which squeezes the rubber so as to close it. Such a clip is very easy to put on, and often closes a tube better than a stop-cock, so that it is very often used in chemistry.

P. I like that, it is so simple and useful.

M. Now we can let our oxygen stream out whenever we wish. I only require to raise the flask containing the

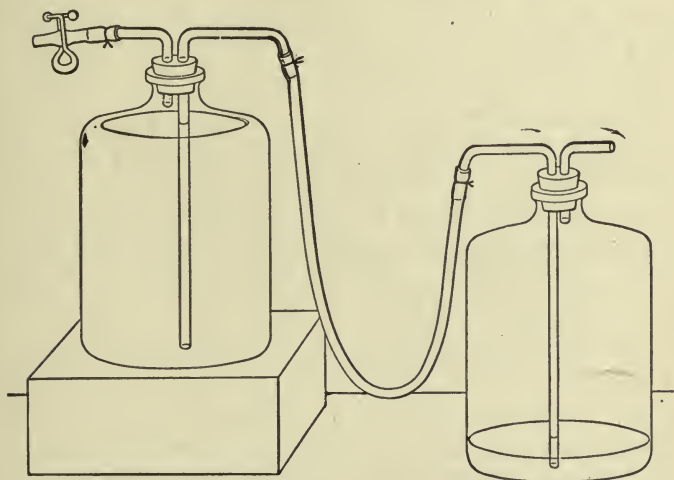


FIG. 28.

water, and the oxygen, under the pressure of the water from such a height, streams out if I open the clip. If I close the clip, the stream stops again. If I don't want oxygen for some time I put the higher flask low again and there is no more pressure.

P. I like that.

M. Now I fix my glass tube with the platinum-point on the gasometer and fasten it so that the point projects into the flame of the spirit-lamp. I let the oxygen

pour out, so that the flame will be blown to the side; at the same time it will be small and pointed and very hot.

P. It only looks a little brighter.

M. I hold a thin piece of platinum wire in it; you see that it not only glows white-hot, but soon melts. Now a pretty round ball is formed at the end of the wire, and if I heat it longer it will fall off.

P. It is so bright that one can hardly see. But you were going to show me the temperature of the hydrogen flame.

M. In this flame it is the hydrogen of which the spirit mainly consists which is burnt. But, to produce a good hydrogen flame, we must make our apparatus somewhat larger and more powerful. As it is at present, it gives out a lot of gas if fresh acid has been put in, but soon less, and a regular flame cannot be obtained. We will make an apparatus that will give us just as much or as little gas as we need.

P. I am curious to see how you will make that apparatus.

M. I take two flasks with the right corks and tubes, exactly the same as the oxygen-gasometer, only that I take rather smaller flasks. One of them is filled with zinc and in the other is dilute hydrochloric acid; the latter is raised higher than the former. When I open the clip which is on the zinc flask, the hydrochloric acid comes through to the zinc, and hydrogen is evolved.

P. But nothing comes.

M. The siphon is not filled yet, and so cannot work. But I only need to blow down the tube of the hydrochloric-acid flask. Now it comes.

P. Yes, now the acid is bubbling. But why did you first put a layer of pebbles in the zinc flask?

M. That you will soon see. I close the clip which lets the hydrogen out. What do you see?

P. The acid goes back again through the siphon into the upper flask. Ah, now I understand. The hydrogen which can't come out any more presses the acid out of the lower flask into the upper one.

M. Quite right. However, as not all the acid can have gone back, because the bottom is uneven, some must have stayed behind, which would work further on the zinc. But now this residue merely remains with the pebbles.

P. That is pretty: a regular automatic machine.

M. I first test my hydrogen to see if it is pure, and then light it. I open the clip so as to give a fairly large flame. For this purpose the clip is provided with a screw (Fig. 29). Now I bring up the platinum tip with



FIG. 29.

the oxygen, and you see how small and pointed the flame becomes. A piece of platinum wire melts far more easily than before. A steel watch-spring that is heated at the end, first glows white-hot, and then burns with lovely streaming sparks, as in oxygen. A piece of chalk that I have pointed begins to glow, and gives such a bright white light that it looks like sunshine.

P. That is a pretty firework!

M. It shows you that the flame of pure hydrogen and oxygen, or, to put it shortly, the oxyhydrogen blowpipe, is really uncommonly hot.

P. That must be about the highest temperature that can be reached?

M. No; the flame is only 2000° C., while between the charcoal-points of an electric-arc lamp over 3000° C. is reached. But still it is a very high temperature, which our furnaces never nearly attain.

P. What a lot I have seen and learned to-day!

19. WATER.

M. To-day we shall study water itself, after having learnt about its constituents and formation. You know that water occupies the greater part of the earth's surface.

P. Yes, about five sevenths.

M. Now, the water which forms the oceans, lakes, and rivers is not by any means pure water, but contains many other dissolved substances.

P. I know that sea-water contains salt; but I don't know anything about other water, or that other substances should be in it.

M. How do you know of the presence of salt in sea-water?

P. By its salt taste.

M. Quite right. Then do all other waters taste the same, rain-water and spring-water, for example?

P. No. I once tasted rain-water; it had a horrid taste.

M. Well, you must conclude from the difference of taste of these other waters that they contain different substances. Here you have a specimen of pure water; just taste it.

P. It tastes just as nasty as rain-water. How is pure water made?

M. By distillation. That is to say, it is first changed

into steam, and this steam is cooled again till it changes into liquid water.

P. But how is the water purer for that?

M. The impurities which are contained in ordinary water do not change into steam, as they are not volatile. I take some ordinary drinking water and add ink to it, so that you can see the impurity quite distinctly; if I distil this black liquid, a pure and clear water comes over.

P. I should like to see that. How is it done?

M. In different ways. We will do it in the simplest way first. I put a cork with a hole in it into this thin-walled flask, and by this means attach to the flask a tube which is rather sharply bent over. I pour my black water into the flask, and heat it till it boils (Fig. 30).

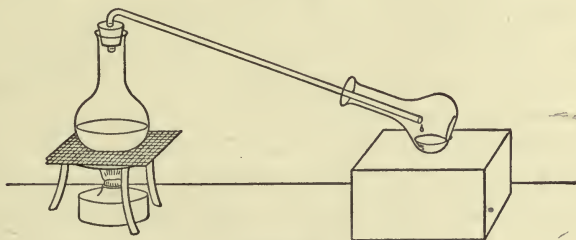


FIG. 30.

P. Now there is some steam in the tube, and now a drop of water is running down; it is really quite clear.

M. We will put another flask over the lower end of the tube, to collect our distilled water.

P. Now this flask is being covered up inside with mist and now the steam is coming out, and isn't condensing.

M. What is the reason of that?

P. The flask has become too hot, and can't cool the steam any more.

M. Quite right. To distil properly, we must provide a cooler. I can do that simply: I place a dish of cold water so that the flask stands in it; that will keep it cool.

P. But if the water gets warm?

M. Then we must stop. You have here an important fact, which is a great question in chemistry: all work must be so arranged that it can be carried on continuously. In order to do this, what is required must be delivered regularly, and what is superfluous must be regularly got rid of. What is being used up here?

P. The water, which changes into steam.

M. Right. Besides that, the heat, which is necessary to make steam. And what is superfluous?

P. The warm water in the dish. That could be changed by letting it out through a siphon and filling it from above.

M. Good; and the water which has distilled over could be replaced in the flask by means of a funnel.

P. But the steam would escape.

M. The tube need only be dipped under the water, and then it is closed. But our cooling could be improved, because if our receiver is only half in water, the upper side remains uncooled, and the steam won't be completely condensed.

P. It must always be turned round so that the cool side is at the top.

M. Then a man or an apparatus is needed to turn it. We must have a cooler that does all that is necessary itself.

P. Then water can be allowed to run over the top side, as well as run out at the bottom.

M. That is better. But there is still a difficulty: the running cold water will mix with the warm water in

the dish, and a great deal of cold water is needed. Can't that be bettered?

P. You are asking a great deal!

M. If a technical or scientific exercise has to be done, you must never be contented with what you have reached, but must always ask: Can it not be made better? And if you find a fault or incompleteness, you must always ask: How can I improve it?

P. I can't do it.

M. It is possible with this *condenser* (Fig. 31). It is made with an inner tube for steam and an outer jacket

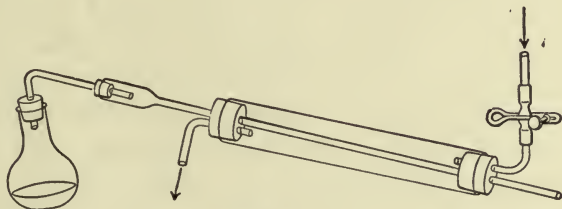


FIG. 31.

for cold water, which can be made of tin. The jacket is provided with doubly bored corks at both ends; the steam-tube passes through one opening, and short tubes are stuck through the others, of which the lower one is for letting in and the upper one for letting out the cold water. A screw clip is used to regulate the amount of water let in; the hot water is let out at the top.

P. Why must the cold water come in from underneath? I thought it would cool better if you let the cold water cool the steam at the upper end.

M. It would be just the opposite, because it would be wasteful, since warm water is lighter; it would always rise upwards and mix with the cold water. But when

the cold water comes from underneath it serves to condense the remainder of the steam. It gets hotter towards the top, and gives up its heat as thoroughly as possible for cooling purposes, for the steam which enters above is condensed by the nearly boiling water, and in this way the cooling water is most thoroughly used, because a useless mixing of the cold water and warm water is avoided.

P. I begin to see how many things you have to think of in setting up a small apparatus.

M. This is the first instance you have had of the principle of opposing currents. While the vapour streams from above downwards, and loses its heat more and more, the cold water streams from below upwards, and absorbs that heat regularly. You will later on get to know a great number of other cases where the same principle of opposing currents is employed. Its use is accompanied with the greatest possible economy.

P. I can't quite understand that, but I'll try to remember, so that I may look out for other instances of the same kind.

M. Now we have collected some distilled water. You can convince yourself that it has exactly the same taste as what I gave you before, and has not the least taste of ink.

P. Why does it taste so bad? Well-water has no particular taste, yet it is pleasant to drink.

M. Because we have always been used from our childhood to drink well-water, in which certain foreign substances are contained, and have grown accustomed to it. Pure water makes a different impression upon our nerves of taste from well-water and we call it unpleasant. Now we will make a wash-bottle.

P. What is a wash-bottle and what is it used for?

M. We must use pure water for our chemical experiments in order not to mix other substances with our solutions. We keep this water

in a vessel in order that we may conveniently use it. First

I cut off a piece of glass tubing half as long again as the height of this flask; and then a short piece. I hold the long

bit in the flame and turn it round till its edge softens; it contracts, and when the opening is reduced to half a millimetre I let it cool. Then I

bend the short tube to an

obtuse angle, and the long one, after the end has cooled, to an acute angle; and lastly I round all the ends. And

now I bore two holes in a cork that fits the flask, stick the tubes through the holes, and my wash-bottle is ready (Fig. 32). Now we will fill it with distilled water, after having washed it out several times.

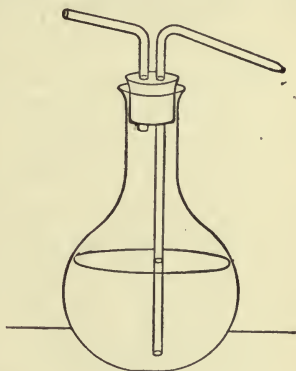


FIG. 32.

P. What is the use of all that?

M. When I blow into the short tube, water issues out of the longer one in a thin stream which I can direct where I like. And if I need more water, I turn the flask upside down and a pretty large stream pours out of the short tube.

P. It looks to me as if you had taken a great deal of trouble for very little purpose.

M. Not at all; for, by the use of the wash-bottle, my daily work is made so much more easy and certain that my trouble is soon rewarded. Every mechanic takes

care to provide himself with the best possible tools, even though they are dear; he is repaid with ample interest because he is able to produce more and better work in the same time. For the chemist a wash-bottle is a suitable tool.

P. But my father has told me that Benjamin Franklin once said that we ought to be able to bore with a hammer and saw with a gimlet.

M. That is not bad advice; it means that one should be able to adapt oneself to anything. But there is a great difference between getting over a difficulty once, and regular work. For example, I might write with this match dipped in ink, if I had no pen, but as I can write better and quicker with a pen, I prefer it. But we have forgotten our water all this time. What is the colour of water?

P. I don't think it has any. It is colorless.

M. Yes, in thin layers it appears colorless, but in thick layers pure water is blue.

P. What is the reason for the difference?

M. Water is so faintly colored that in thin layers the color is not recognizable. But you learned long ago that the color is more distinct the thicker the layer. Pure water in a white bath shows the blue color distinctly.

P. The next time I take a bath I will look out for that. But the water in the river is not blue, but brown.

M. The reason for that is that the water in the river contains foreign substances, the color of which is brown. Sea-water is generally pure, and has a blue color; but if it is mixed with brown substances the mixture looks green.

P. But sea-water is not in the least pure, for it contains salt.

M. Quite right; but salt is colorless, and so it doesn't alter the color of the water. What is the density of water?

P. I remember that. Its density is 1, for it serves as the standard of density.

M. Good; that is, its density at $4^{\circ}\text{C}.$: at all other temperatures it is less. While all other substances expand by heating, water contracts between 0° and $+4^{\circ}\text{C}.$ And above that temperature it expands.

P. I should like to see that.

M. There are several ways of showing it. Take a wooden bucket, bore a hole in the side near the bottom, and cork a thermometer into the hole. Then fill the bucket with ice-water in which pieces of ice are floating, and let it stand (Fig. 33). After some time the thermometer below will show the temperature $+4^{\circ}\text{C}.$, while another thermometer dipped in the water at the top will stand at 0° . Explain that to me.

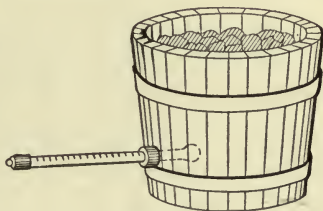


FIG. 33.

P. Because water at $4^{\circ}\text{C}.$ is heavier, and must collect at the bottom.

M. Something more might be said about that, but it is right in the main.

P. How would this do; would this not be simpler? If water were enclosed in a thermometer-tube, it would contract between 0° and 4° , and then rise again. Could not a water-thermometer like that be made?

M. Yes, of course. Here I have a glass tube of pretty

narrow bore, about half a millimetre. I heat the end till it melts, and blow in; I make a bulb just like a soap-bubble. I fasten on the upper end a cork with a wider piece of tubing, which I fill with water (Fig. 34). I first warm the bulb slightly, and air-bubbles escape through the water above. Then I cool it down again, and some water is sucked into the bulb. I boil this water, and when I take away the flame the water rushes into the bulb and fills it. Generally a small air-bubble remains, but that is easily removed by heating the water, and then cooling it; the bubble is pushed out, and on cooling the water fills the tube.



FIG. 34.

P. But how can a scale be fastened on?

M. I take a piece of an old millimetre scale or some divided paper, or something of that sort, and stick it on the tube with sealing-wax. After my water-thermometer has taken the temperature of the room, I remove the upper tube. Now I will trust the apparatus in your hands, and also a thermometer. Tie them both together so that you can read both scales easily, and place them in a large dish of water. Now notice where the mercury in the thermometer stands and where the water stands. Now put some ice in the water so that the temperature sinks about a couple of degrees, and stir it for at least five minutes till the water-thermometer has got steady, and write down the readings you find. Go on till the temperature is nearly 0° . Tell me to-morrow what you have found.

P. I'm afraid that what I have done is not worth any-

thing. I played the whole afternoon with the thermometer, but I couldn't find out that the volume of water was smallest at 4° .

M. What did you find?

P. That the water sinks, to begin with, as the thermometer falls, but at about 8° it stops, and if I cool it, it rises again. I always get 8° as the temperature of the smallest volume.

M. What do you think is the reason for that?

P. I didn't think of looking for a reason. I only thought that I had read it wrongly, but I always got the same.

M. Then your readings were right. What quantity were you measuring?

P. The volume of the water.

M. No, you were only measuring the position of the water, and drawing a conclusion from that as to its volume. Before you can draw a conclusion from the position of the water as regards its volume, you must make sure that the capacity of the thermometer-bulb always remains the same. Are you quite sure of that?

P. Let me see. Yes, I always found the same position at the same temperature.

M. Very good. But from that you can only conclude that at the same temperature the capacity was the same. Do you see now?

P. You mean that the glass of the bulb had expanded by heat? That couldn't make any difference, because the glass is so thin that it makes only a very small fraction of the volume of the water. And the small expansion of this small volume couldn't make a great difference.

M. You have made a mistake in reasoning. You

have supposed that the alteration of the volume of the glass had to be considered? That is not true. You should have considered the increasing volume of the glass bulb, which is the same as that of a solid ball of glass of the same size as our thermometer-bulb, and is nearly as great as the expansion of water.

P. But the ball is not solid.

M. Think of a solid ball heated uniformly to any high temperature; will the interior be in a state of strain or in equilibrium?

P. I think it will be in equilibrium, for it expands uniformly.

M. Right. Now think of this ball as consisting of a number of hollow balls fitting each other accurately, like the layers of an onion; would there be any difference if such a ball were heated?

P. I see no reason. Ah, now I understand: the outside layer would expand exactly as if the inner layers were not there, just as if it were a solid ball. That's very ingenious.

M. Now you see the reason why you found the point of the smallest volume of the water too high. If the water hadn't expanded at all it would have sunk in the stem, because the volume of the bulb would have increased. It is only when the expansion of the water is exactly even with that of the glass that it remains stationary in the stem; and that is at 8° . As you see, you have been examining the difference between the expansions of water and of glass, and in order to find out the former you must know the latter, but that is not easy to find out.

P. Oh, bother! I thought I was doing the thing well and I have been wasting my time.

M. Not wasting, because you have learnt how much .

there is to think about for every experiment before you know how to interpret it.

20. ICE.

M. Yesterday you learned some of the properties of water; which do you remember best?

P. The greatest density of water and the experiment about that. I tried it with a pail and it came out all right.

M. Good. It is important in nature that the density of water has its greatest value at 4° ; that is called the temperature of maximum density.

P. Why should such a small difference be so important?

M. When still water, for instance a lake, is cooled on the surface, the colder water sinks till the whole of the water has reached the temperature of 4° . Then the cold water stays above till it freezes, while below the temperature 4° persists, just as in your experiment with the pail (page 159).

P. Then fish aren't so cold, after all?

M. That is of no great importance; but if it were not the case, ice would be deposited at the bottom of the lake and it would freeze through and through, instead of being coated with ice only on the surface. The fish would, of course, die, and in spring it would be much longer before all the ice melted. In quickly running rivers where the water is thoroughly mixed it sometimes happens in a hard winter that all the water is cooled below zero, and then ground-ice is formed, which floats to the top when its mass has sufficiently increased.

P. I should have thought that the lake would become covered with ice, for ice floats upon water.

M. There is another condition which protects lakes from freezing. This brings us to the properties of ice. You know that water changes to ice at 0° . But now I will show you that that isn't always the case. I mix some pounded ice with a little salt, and the temperature falls below 0° , and is lower the more salt I mix with the ice. Now give me your water-thermometer and the mercury-thermometer. The temperature of my cold mixture is -5° . I'll put the bulb in and let the water cool itself down.

P. It will freeze and the bulb will be sure to burst.

M. Then you can blow a new one. But you needn't be afraid; it won't freeze.

P. Why is that?

M. As long as there is no ice present water can be cooled considerably below 0° without freezing. Only, when you bring it in contact with some ice, the water becomes solid.

P. Why is that?—I beg your pardon, I must ask the question differently: What else is it connected with?

M. That is a difficult question to answer. Now remember that the temperature 0° always persisted when water and ice were simultaneously present. If you cool water alone below 0° ice *may* be formed, but it is not necessary that it should be. That is a general statement; even though the conditions are present for the formation of new substances or forms, these do not generally appear of their own accord, but the point of change may be more or less exceeded. Only, this becomes impossible when these new substances are present, for they, being already in existence, increase.

P. That is no explanation; it is only a description.

M. Quite right. You know now under what circumstances such phenomena become manifest, and what their relations are. What more do you wish? When you have learnt more about chemistry you will get to know of other relations, and be able to look at these phenomena from many points of view. That is all that we can hope to learn from science, and it is surely enough. In order that we may be able to talk of such things in future, I may tell you that what you have seen with water is supercooling; a more general word is supersaturation.

P. I see I have a great deal to learn still.

M. So have we all. Then ice floats upon water; what conclusion can you draw from that?

P. That ice is lighter than water.

M. Do you mean that water loses weight when it freezes?

P. No. Water which is displaced by ice weighs more than the ice.

M. When the ice is completely immersed in the water. Or in other words, when water freezes the resulting ice occupies a greater volume than that previously occupied by the water. There is a good deal of difference: ten volumes of water give more than eleven volumes of ice. That is a peculiarity of water. Most other substances contract on freezing, so that the solid sinks in the liquid.

P. Has that any connection with the expansion of water below 4° ?

M. That is a question which has given rise to much speculation. But no satisfactory explanation has yet been found. Have you ever seen water beginning to freeze?

P. Oh, you mean when only a little of it is frozen? Yes, long needles appear on the surface. I have often seen it on the puddles.

M. These are crystals, for ice is a crystalline body.

P. I know, I have often seen large snow-crystals. They look like stars with six rays, or six-sided plates.

M. Quite right. Here are some photographs of snow-crystals (Fig. 35). The frost on the window-pane consists of ice-crystals.

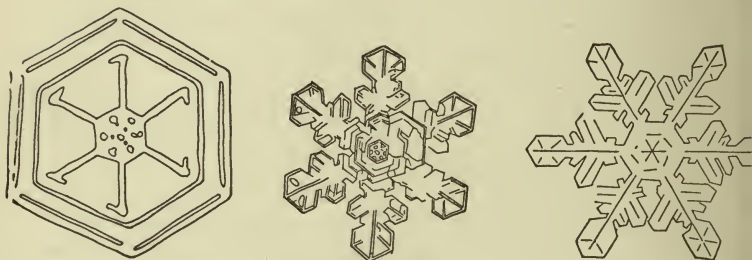


FIG. 35.

P. But their shape isn't regular.

M. Because the water freezes too quickly on the pane for the crystals to have time to form. But sometimes where the pane is almost quite clear you will see pretty regular crystals which have deposited slowly from the water in the air.

P. Then hoarfrost also consists of crystals?

M. Yes. You have seen them glistening in the sun, which is reflected on their surfaces. A sheet of ice on a frozen pond can also be shown to be crystalline. Ice is as blue as liquid water.

P. But snow is quite white! Stop, I know why; because it is so finely divided (page 9). And I remem-

ber that large blocks of ice that you see on the street look quite blue.

M. Large masses of ice called glaciers slip down from high hills which are covered with everlasting snow; when they move they split, and in the cracks, or crevasses as they are called, they look beautifully blue.

P. I suppose because the light has to penetrate through thick layers of ice.

M. Quite right. Now we will look at some ice melting. I take a thick iron plate and lay it upon a tripod above the spirit-lamp. Now I take two similar beakers or flasks and put some ice into the one, and into the other an equal weight of water at 0° . I place these beakers symmetrically on the plate, so that each gets the same amount of heat from below; and in each I place a thermometer. Now we can proceed with the experiment.



FIG. 36.

P. What is to be learnt from that?

M. That ice can absorb a lot of heat without becoming warmer.

P. How can that be?

M. Look here: the thermometer in the water has risen from 0° to 20° . The one in the ice is still at 0° .

P. The reason for that must be that ice is present with the water, and therefore the temperature must stay at 0° .

M. Quite right; as much heat must have entered the ice as was necessary to raise the water from 0° to 20° , and yet the ice is no warmer. What has happened to the ice?

P. Some of it has melted. So heat is really used up by the melting of ice?

M. Exactly. What is heat?

P. One kind of energy or work. So it requires work to change ice into water.

M. Quite right. Before people had acquired a conception of energy, they were very much surprised at this, and said that although heat was not perceptible to the thermometer it must nevertheless be present, and only lay concealed; they, therefore, called this heat latent heat, from *lateo*, I lie hid. Even now this name is used, although the former false conceptions have been replaced by correct ones.

P. I don't quite understand that.

M. You know that in general, work or energy is used up in producing a change of state; so it is here. For example, when you grind a piece of sugar to powder you can't do that without work, just as when you break a rod or bend a wire. In the same way melting requires work, and this work is derived from simple addition of heat.

P. Can the work be done in any other way?

M. Certainly. If two pieces of ice at 0° are rubbed

together they melt. Now the ice has melted and the thermometer has risen to a little above 0° . The other thermometer shows nearly 80° . Now notice. The amount of heat required to raise 1 gram of water through 1° is called a *calory*, abbreviated cal. To raise 1 gram of water from 0° to 80° , 80 cal. are required; to raise 200 grams of water to 30° , $200 \times 30 = 6000$ cal. are required. The amount of heat is measured by multiplying the rise of temperature by the weight of the water.

P. I understand that. But if the water grows colder?

M. Then heat, equal to the product of the lowering of temperature multiplied by the weight of the water, has escaped. Now the water has become 80° warmer by absorbing the heat required to melt an equal weight of ice; so that each gram of water has absorbed 80 cal. and each gram of ice exactly the same quantity. And it follows that each gram of ice requires 80 cal. in order to melt to water at 0° . In other words, 80 cal. are the work of melting, or the *heat of fusion* of ice. The old name which I explained to you before is the latent heat of water.

P. But this number refers to 1 gram of ice.

M. Quite right. Such numbers are generally referred to unit of weight, because then it is only necessary to multiply by the weight in order to find the value for a given quantity. Let us make an application of this. We will weigh 500 grams of water into a beaker, and after measuring the temperature with a fine thermometer we will drop in a piece of ice. The temperature is 18.7° and the ice weighs 34 grams. Now I put the ice into the water, and stir it carefully with the thermometer until all the ice has melted. The thermometer has fallen to 12.4° . You can calculate the latent heat of water from this.

P. I'll try. 500 grams of water have lost $18.7 - 12.4 = 6.3^{\circ}$ so that $500 \times 6.3 = 3150$ cal. have been used. That heat melted 34 grams of ice, so that each gram took 93 cal. Is that right?

M. Pretty nearly, but not quite. By heat of fusion is meant the heat required to change 1 gram of ice at 0° into water at 0° . The ice-water, however, gets heated up with the rest of the water to 12.4° , so that you have calculated the heat of fusion higher than it should be.

P. Yes, I see that, but how can it be corrected?

M. By bringing everything that happens into the calculation. You were right in supposing that 500 grams of water had lost $500 \times 6.3 = 3150$ cal. But of this $34 \times 12.4 = 422$ cal. have been used in warming the melted ice, and only the difference, $3150 - 422 = 2728$, has been used for melting the ice. This difference divided by 34 gives 80 cal. as the heat of fusion of ice.

P. I see again that making experiments is much easier than drawing the right conclusions from them.

M. But even here we haven't taken everything into consideration. We have paid no attention to the fact that not only the 500 grams of water were cooled down, but also the thermometer in the beaker. Then we just noticed that the beaker with the cold water is gradually warming itself in this room, so that while the ice was being melted, heat was entering from outside, and the lowering of temperature was therefore too small. Even that is not all that we ought to have considered, but I will refrain from adding more so as not to confuse you.

P. I'm rather muddled as it is, and can't understand how there are people who know all these things and can do them correctly.

M. You can neither use a lathe nor paint, and while you were learning to cycle you found that very difficult. To make correct measurements is an art in itself which has to be learnt, and no one ever learns it thoroughly. Exact measurements prove the heat of fusion of ice to be 81 cal.

21. STEAM.

M. To-day we shall speak about steam.

P. Water again! If we are going to spend as much time over other substances, I shall never have done with chemistry.

M. Water is only an example by means of which we learn the behaviour of substances under different circumstances. All the so-called laws, for example those relating to melting and solidifying, are the same with other substances, so that you don't need to learn them again.

P. But why did we choose water as an example?

M. Because water has been more studied than any other substance and is therefore best known.

P. But why was water so carefully studied?

M. Because it occurs in such large quantity on the earth. Just think how differently the surface of the earth looks when the temperature is below 0° . Of course the reason is that water freezes at 0° . The difference isn't merely the appearance of ice and snow, but also the temporary cessation of life in plants, caused by the fact that the sap can no longer flow.

P. Yes, I see that water affects almost everything.

M. Besides, since water is so abundant, it is easier to obtain purer than other substances, and so it is especially

adapted as a standard with which to compare properties. You have learned this use of water already for the thermometer and for density; and for many other properties water serves as a standard. And that of itself is a reason for getting to know the properties of water more thoroughly than that of other substances. We shall therefore take up, to begin with, the boiling of water.

P. Is there anything special about that? I have been taught that water boils at 100°C . whether a large or a small flame is below it.

M. Let us see. I boil some water in a flask and close the mouth with a cork while it is boiling; what will happen?

P. The pressure of the vapour will rise and the flask will burst.

M. Quite right, so I take the flame away and let it cool down. But as it cools too slowly, I will pour some water on the flask. What do you see?

P. How funny! The water is beginning to boil again.

M. I pour more water on it and the boiling begins again. Now it is so cold that I can hold it in my hand without burning it; the water can't be hotter than 50° and still it boils whenever I pour cold water on the top of the flask.

P. I can't believe that in the least.

M. Why not? You must believe what you see.

P. But I was taught that water boiled at 100° , and now it's boiling at a much lower temperature.

M. Well, what conclusion do you draw?

P. That water can boil at all possible temperatures. But that is nonsense.

M. Why?

P. Because the water always showed the temperature 100° whether the flame was big or small.

M. Quite right. But when you see that a phenomenon changes you must conclude that some condition, closely connected with the phenomenon, has changed. Now think what is the difference between the boiling, now and before?

P. Heating made the water boil, but now it boils when it is cooled.

M. It can't be only cooling, because then water would always keep on boiling when you took away the flame. Is there nothing else you can think of?

P. Yes, you corked the flask. But how can a cork make the water boil?

M. Take the cork out.

P. That's not easy. And it hisses as if air were being sucked in.

M. So there is a vacuum in the flask. Now think why.

P. I begin to see. The steam blew out the air, and then you corked the flask so that no more air could enter.

M. Quite right. The flask contained only water and steam, and when I poured cold water on it, the steam was condensed, the pressure was lowered, and the water was obliged to boil.

P. But does water really form steam at every temperature if the pressure is lowered?

M. Water boils at every pressure, and a definite temperature corresponds to each pressure. It boils at 100° only when the pressure is exactly that of the atmosphere. On high mountains where the pressure is much lower boiling water is not hot enough to cook meat

P. I should like to see that.

M. I can show you something like it. I close the flask with a perforated cork through which passes

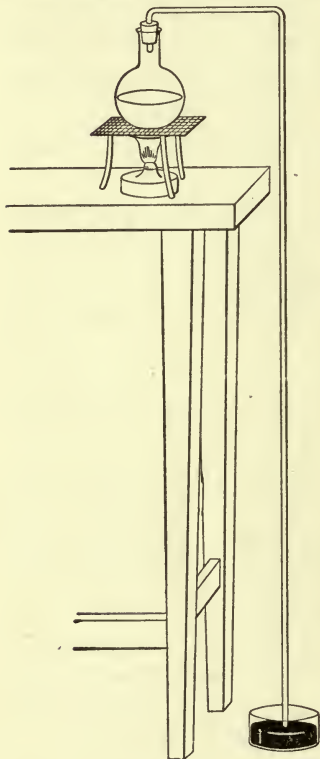


FIG. 37.

a doubly-bent glass tube, one of the limbs of which is 80 cm. long (Fig. 37). Its end dips in a basin of mercury. Now I heat the flask again; and you can hear the air bubbling through the mercury. Now the noise changes; it rings almost like a metal.

P. What is the reason of that?

M. The steam is now almost quite free from air, and when it passes into the cold mercury it suddenly changes to liquid water, and the sides of the bubble hit each other. As long as air was present the sides couldn't come together, but now it is metal hitting metal. Now I take the

flame away and you see that when I pour on cold water, the boiling begins again.

P. What is the use of the tube that dips in the mercury?

M. Notice what happens when I pour on cold water, the flask.

P. At first the mercury goes up quickly, and then it

falls when the boiling begins; but I see it stands higher than at the beginning.

M. Now you see everything happens as I told you it would. The higher the mercury is sucked, the smaller the pressure on the inside of the flask. It was highest immediately after I had poured water on it; but when the water began to boil steam was formed, which again filled the space and increased the pressure, and the mercury fell.

P. But why did the level of the mercury always become higher each time?

M. Because the water in the flask became colder each time I poured water over it, and its vapour pressure decreased. It boiled only when the pressure was made still smaller.

P. So that boiling takes place when the pressure on the water is less than the vapour pressure. I see you nodding, so that's right. But what is vapour pressure? There is never anything but vapour in the flask.

M. Imagine an empty space; of course there is no pressure in it. Now introduce some water; part of the water changes to steam. This goes on till the space is filled with steam to a certain extent, and then evaporation stops. And vapour is formed till it has a certain definite density in the space, and exerts a definite pressure. The density and the pressure depend only on the temperature. At 0° the pressure is very small and could only raise the mercury 4 mm. high; but at 100° it is so great that it can overcome the whole pressure of the atmosphere.

P. And above 100° ? Can water be made hotter?

M. Certainly; only then the pressure must be increased by confining the vapour. As you know, this occurs in

a boiler. If the pressure is twice as high as the atmospheric pressure, the temperature of the water is 121° . And if its temperature is 180° , the pressure is ten times as great. The steam-engine is contrived to utilize this pressure. You can see on every steam-boiler an apparatus which looks something like a clock-face and is called a gauge, or a manometer; it measures the pressure.

P. I have often seen it. Why is the pressure measured in pounds?

M. It means pounds per square inch. The pressure of the atmosphere, that is, the pressure which the air exerts upon the surface of the earth, is 16 lbs. per square inch. But steam is used for heating, as well as for driving, steam-engines. Do you know why?

P. Because its temperature is 100° .

M. That is not all; it can give up far more heat than water at 100° .

P. That is the same as with water and ice.

M. Quite right. To change water at 100° into steam of the same temperature requires a great deal of work which can be added in the form of heat. We can make an approximate measurement. We will first heat a known weight of water over the lamp, and by measuring the time we will calculate from its amount and from the rise of temperature how much heat the lamp gives it per minute. Then we will boil the water over the same lamp and measure the time that it boils; then we will weigh it again, and from its loss we will find how much vapour has been formed; then we can calculate how many calories are required to evaporate 1 gram.

P. I should like to do that. What sort of dish shall I take?

M. Take a flask; we shall weigh out 200 grams of water. Now we will put a thermometer into it; its temperature is 13° . The lamp has been burning for some time and the flame has become regular; I place it below the flask, and let it *burn* for fifteen minutes. Now what is the temperature? Remember to stir before you read.

P. 78° . That is 60° in fifteen minutes or 4° a minute. As there were 200 grams of water, the lamp gives 800 cal. a minute.

M. Quite right. Now the water begins to boil and I look at my watch again. In ten minutes I take the lamp away and let the flask cool. On weighing it, it has lost 14 grams. How many calories does that require to produce 1 gram of steam?

P. Ten minutes for 800 cal. makes 8000 cal., and dividing by 14 gives 571 and a fraction.

M. Fairly good. The right number is 537 cal. The reason why we found it too high is that the flask while it was at 100° has been losing more heat than while it was being heated up from 18° to 68° .

P. Yes, I can quite imagine that all kinds of things must be thought of in order to get correct numbers.

M. That is true; the measurements are much more difficult than with ice. But we won't trouble about that at present. As you see, the heat of evaporation of water is nearly seven times as great as the heat of fusion of ice.

P. Yes, the heat of fusion was 81 cal.

M. For this reason steam can be used to convey heat from one place to another without the necessity of carrying much weight. The vapour is produced in a boiler, and led through pipes to where the heat is wanted. In schools and public buildings, heating with steam is

often adopted, and on turning a stop-cock, you can make it either cold or hot.

P. But when the steam has given up its heat, it goes back to liquid water. What becomes of the water?

M. It is led back to the boiler. The water makes a circular tour through other pipes; but the heat goes from the boiler to those places where it is wanted and stays there. It is much the same as when the piston of a locomotive conveys motion from the engine to the wheel, and again comes back; but the work stays there.

P. Is there steam-heating in railway carriages? One often sees steam escape between the carriages in winter.

M. Yes, the steam which has escaped from the cylinder of the locomotive is used for that purpose, after it has done its work.—So now we know water in all its three forms, but we have not nearly done with it. Of its other properties, perhaps the most important for us is its power of dissolving substances. Do you remember what you learned about that?

P. That water becomes saturated when it dissolves anything.

M. Be more exact.

P. When you put into water anything it can dissolve, only a definite quantity goes into solution. And when the water can dissolve no more, it is said to be saturated.

M. But suppose you were to take three times as much water?

P. Then three times as much substance would dissolve.

M. Quite right, but that is only at some definite temperature. If you were to heat the solution—

P. Then it would dissolve more.

M. That is not always right. It is true that most

substances behave in that way, but there are some that dissolve equally well at different temperatures. Common salt is such a substance; it is nearly equally soluble in hot and cold water.

P. Are there any substances which dissolve better in cold than in hot water?

M. There are, but they are rare.

P. Which substances dissolve in water, and which don't?

M. Strictly speaking all substances dissolve in water; but there are many which dissolve so slightly that very accurate tests are necessary to find out that they do.

P. Surely glass is not soluble in water?

M. Yes, indeed; although it is only very sparingly soluble.

P. How can I see that?

M. Take some beet-root juice and put it on a piece of glass. It stays red. But if you powder the glass in a mortar along with beet-root juice, the juice turns blue and green. The reason is that the glass dissolves and acts upon the juice so as to turn it green.

P. Why must the glass be ground up in a mortar?

M. The solution takes place faster when the surface is increased.

P. I hadn't thought of that. But stones don't dissolve in water.

M. All river- and well-waters contain dissolved substances. You can see that from the deposit in the tea-kettle where the dissolved substances settle out as a grey crust which is called fur.

P. Yes, I have just seen them removing that fur. It stuck very tight.

M. Well, these dissolved substances came from the rocks through which the water flowed before it reached

the surface. For, to begin with, the water was pure distilled water.

P. How could that be? Who distilled it?

M. Well-water comes from rain which falls on the surface of the earth, sinks in, and collects in deeper places. Where does rain come from?

P. From the clouds.

M. Yes, and clouds are formed by the condensation of water-vapour out of the air. So that rain-water is really distilled water, indeed quite freshly distilled. When you see it it has generally run over a roof, and carries all the dirt with it that has collected on that roof since the last shower. How does water come into the clouds?

P. It evaporates from the surface of the earth, and is driven about by the wind.

M. That is right so far, but to evaporate it requires heat, and you have just measured how much. Where does it get the heat from?

P. Is it from the sun?

M. It is. Since the rays of the sun warm whatever they fall upon, they also form a kind of energy which is called light, or *radiant energy*. The sun gives the work which evaporates the water, and lifts the vapour into the air. When the water falls again as rain or snow, the work is partially restored; for example, it can drive a mill.

P. So mills are really driven by the sun?

M. Yes, for if it stopped shining all streams would stop running. Besides, windmills are driven by the sun, for wind is the result of its action.

P. How it all hangs together! I look upon the sun and the rain with quite different eyes now.

M. You will learn many more such connections.

Now let us get back to the property which water has of dissolving substances. When water has dissolved any substance, it is said to form a solution. Such solutions are much more in use than the substances themselves.

P. Why?

M. Because of their chemical action. Solid substances do not act at all on each other, or only very slowly and incompletely. In order that they may act upon each other chemically they must be brought together in the liquid state. This can happen in one of two ways; they may be melted or they may be dissolved. Melting requires a high temperature, as a rule, which is not easily attained, whereas it is easy to make a solution. Moreover, many substances do not stand a high temperature without changing.

P. I begin to see that water is almost the most important thing in the whole of chemistry.

M. Not alone in chemistry, but also in daily life. All food contains more or less water; tea, coffee, milk, wine, beer, are solutions and to some extent mechanical mixtures of various substances in water; blood and all other juices of the body are also aqueous solutions. So is the sap of plants; you know that every plant dies when it is dried, that is, when water is removed from it. And that is also the case with animals.

P. I shouldn't have dreamt that water was such an important substance; you might even say, No water, no life!

M. Of course you can also say: No oxygen, no life; no nitrogen, no life; no iron, no life, and so on. Life is such a very complicated affair that many conditions must be fulfilled before it occurs. You can picture it as a stretched chain consisting of different kinds of links;

when one of the links is broken, the chain breaks, no matter how strong the other links are. In the same way life stops if any one of the necessary factors is wanting, so that none of them can be called the most important.

22. NITROGEN.

M. To-day we shall learn something more about air.

P. We are taking up all the elements one after another; first fire, then water and earth, and now air.

M. The old Greeks called them elements because they were universal and their importance could not be overlooked. And as we too are considering the most important things we naturally come to them. What do you know about air?

P. That it is a gas, but not an element; it is a mixture of one-fifth of oxygen and four-fifths of another gas—

M. Which is called nitrogen. I told you, too, that nitrogen, like oxygen, has neither color, odor, nor taste, and that it differs from oxygen in not supporting combustion. It is not combustible, and so differs from hydrogen.

P. Then does nitrogen combine neither with oxygen nor with other substances?

M. Not as a rule; nitrogen is an unsociable character—it likes solitude, doesn't care to unite with other elements, and, even after it has united, it separates as soon as it can. That is the reason why air consists mostly of uncombined nitrogen. For as it is a gas there is no other place for it.

P. Doesn't it dissolve in water?

M. Very little, even less than oxygen. We will make some nitrogen. How can that be done?

P. We require only to separate nitrogen from the air.

M. Quite right; how shall we do that?

P. Oh, I suppose by burning something in the air; a candle?

M. That has several disadvantages. First of all, other gases are produced at the same time which remain mixed with the nitrogen; and second, a candle goes out long before the whole of the oxygen has been removed. Here is another means of removing oxygen: it is *phosphorus* (see page 105). It has the property of using up all oxygen even at ordinary temperature. I place in a test-tube a piece of phosphorus which has been made fast to a wire by melting. Then I invert the test-tube over water (Fig. 38). You see that a white vapor flows down from the phos-

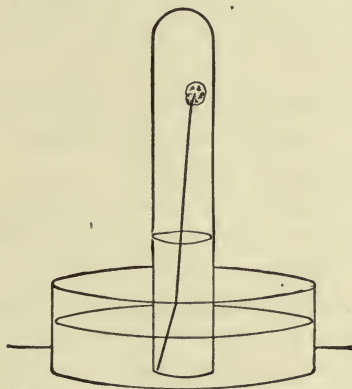


FIG. 38.

phorus; it consists of the products of oxidation and contains oxygen. At the same time the water begins to rise slowly, and after about an hour the cloud is no longer visible, showing that all oxygen has been used; a fifth of the air has disappeared. I have here a flask in which phosphorus has been kept since yesterday. It now contains only nitrogen.

P. It looks exactly like air.

M. You will soon see that it is not. I dip in a burning splinter, and it goes out just as if it were plunged into water.

P. Give me some phosphorus; I want to repeat that experiment.

M. I would rather not, for phosphorus catches fire very easily, and, moreover, is very poisonous. I will tell you another plan. There is a compound of iron, a sulphate; it is a green salt. If you dissolve it in water and mix the solution with lime you get a thin paste which takes up oxygen very quickly. I will make such a paste in this large flask, and, after I have corked it, I shake it thoroughly. If I place its neck under water and take out the cork, water enters—a sign that some of the air has disappeared.

P. Let me try with this splinter. Quite right. It has gone out.

M. There is not much more to show you with nitrogen, as it does not combine with any common substances.

P. Is it light, like hydrogen?

M. No; since it is the chief constituent of the air it has about the same density as air. It is lighter than air because oxygen is a little heavier.

P. Then nitrogen appears to be a sort of indifferent element, which is unnecessary for changes on the earth.

M. No, that is by no means the case. Nitrogen is equally important in peace and in war, first because it is a constant constituent of all living creatures, animals as well as plants; and second because compounds of nitrogen form gunpowder, artificial dyes, and innumerable other substances which are equally important for industry and daily life. While free nitrogen costs nothing, because you can have as much as you like of it in the air, combined nitrogen has a fairly high value; it costs about 10 cents a pound.

P. Why don't they make compounds using the nitrogen of the air?

M. You will find a serious difficulty there. Making the free nitrogen of the air combine with other substances is such an expensive operation that the price of the compound is prohibitive.

P. How can that be? It costs nothing to change oxygen or hydrogen into compounds; the change happens by itself.

M. There is the difference. With nitrogen it doesn't happen by itself. I see you ask why not. The answer is that hydrogen and oxygen when they enter into combination give out energy; indeed, you saw how much heat is produced by their combination. But to make nitrogen combine, work or energy must be spent. And since work is never a free gift, combined nitrogen has a much higher value than free nitrogen, although it is the opposite with hydrogen.

P. But not with oxygen?

M. Plants make free oxygen; we shall come to that later. And because free oxygen can't exist in plants, but spreads itself through the air, it costs nothing. If oxygen were a solid or a liquid substance it would be collected just as we gather grain and fruit, and would be sold.

P. So the value of these substances does not lie in themselves, but in the work which is connected with them.

M. The thought is right, but you haven't expressed it correctly. Different substances do not exist without carrying with them the corresponding amounts of work or energy; therefore you cannot talk of them without speaking of this energy. The fact is this: in certain cases the uncombined elements contain more energy than their compounds; in other cases, as with nitrogen, the opposite is the case. According as one or the other

relation prevails, the elements or the compounds have the higher value.

P. But their value consists really in their energy.

M. Yes, that is right on the whole.

P. How does it happen that compounds of nitrogen are important for war, as you said, because gunpowder is made from them? Has that anything to do with the question of work?

M. Of course. A gun is also a machine for doing work.

P. No, indeed! It is used for destruction and not for work.

M. What you call destruction is also work. The object is to give to the ball a certain high velocity, and in order to do that, as you know from throwing stones, a good deal of work must be expended.

P. Yes, now I understand. With gas-engines, of which you spoke to me before, an explosion is also used to make work.

M. Quite right. And if large blocks of stone or of ice have to be got rid of (and that involves a great deal of work), they are blown up with powder, as you know. There you have the work done with the powder before your eyes.

P. Yes, I see that. But what has it all to do with nitrogen?

M. Well, in compounds of nitrogen there is more work than in free nitrogen, and so these compounds can be used to do work.

P. Oh, that is the reason, is it?

M. Yes; at least a partial reason.

P. Please answer this question that I wanted to ask before. You said that nitrogen was so easily produced from its compounds. How does it happen that there is any combined nitrogen, and that it is not all free?

M. That is a very good question. The answer is that by many kinds of work which are available in nature, free nitrogen is brought into combination. For example, many plants, like peas, beans, lupins, and vetches, have the property of using part of their work in causing nitrogen to combine. When an electrical discharge, which you call lightning, passes through the air, nitrogen also enters into combination. Besides that, people are very careful not to waste combined nitrogen. The dung of animals contains a large quantity, and the farmer spreads it on his fields, where it is absorbed by plants.

P. So that is why they spread it on fields. I could never see why that nasty-smelling stuff could do any good to plants.

M. Besides containing combined nitrogen, manure contains other substances which plants require, but nitrogen is the most important because it is the dearest. Moreover, though manure could be made to have no smell, it would not help us, because the evil-smelling substances contain nitrogen, which would be lost if they evaporated.

P. So the bad smells come from nitrogen?

M. A good many do. Do you know the smell that wool gives off in burning?

P. Yes; it is abominable.

M. Many other substances give a similar smell; for example, horn, flesh, leather, and feathers. All these substances contain nitrogen, and that forms a means of recognizing them. Wood and sugar and starch also give disagreeable smells when they burn, but they haven't this extremely unpleasant odor; they contain no nitrogen.

P. When milk boils over in the pan it smells as unpleasant as burnt hair. Does it contain nitrogen too?

M. Certainly; casein, which is contained in milk, is a compound of nitrogen.

P. Is casein contained in cheese?

M. Yes.

P. Old cheese has a different kind of smell.

M. That is also due to its containing compounds of nitrogen.

P. Do all nitrogen compounds smell bad?

M. Not all, but most of them. But nitrogen is not the only element that has this unpleasant property. Many sulphur compounds have a disagreeable smell, though of quite a different character.

23. AIR.

P. You told me yesterday a great deal about the compounds of nitrogen, but you didn't show me a single one. There must be hundreds of them.

M. That is quite true. You will have to wait till later to learn about the individual compounds, because they exhibit pretty complicated relationships. For the present we have still much to learn about free nitrogen.

P. I thought there wasn't much to say about it; you said something of that sort.

M. Yes, so far as concerns its properties as an element. But because nitrogen is the chief constituent of the air, we must take air as our subject. Our whole life and everything that we do takes place in air, and so we must learn about its properties and know how to interpret them rightly, in order that we may not make frequent mistakes.

P. Yes, no one can live without air. But you told me it was the oxygen which was necessary to life, and that animals are suffocated when placed in nitrogen.

M. Quite right; but we will not discuss that again.

Air, however, is a gas; it is the best known and most widely spread of all gases. For that reason we will now study the properties of gases, taking it as an example.

P. I'm glad of that, for I must say that gases always strike me as queer. It is easy to see and grasp solid and liquid things; but whether a flask contains hydrogen, or oxygen, or ordinary air, I'm sure I can't tell. For all I know there might be nothing in the flask.

M. Yes, I quite believe you; for as gases are hardly ever visible, people don't generally know much about them. So I will show you something. You know that we live surrounded by gas, by air. A wind or a storm will teach you that air is a substance; just as a solid or liquid body in motion can move, throw down, and break other bodies, so also can air in motion.

P. Why can't we see air?

M. Because we are surrounded by it. Fishes can't see the water in which they swim. But when air is surrounded with water it becomes visible. I blow air through this tube into a tall glass full of water. Now you can see little quantities of air, as round bubbles, quite well (Fig. 39).

P. But I see nothing in the bubbles themselves.

M. Of course not, because air is transparent. You see nothing in the water in the glass; you only recognize the surface which divides the water from the air in the glass. It is exactly the same with the air-bubble.

P. But I can't understand in the least how you can see air in water when they are both transparent,

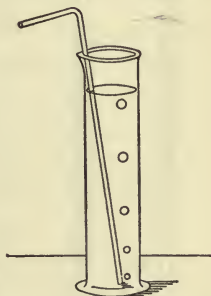


FIG. 39.

M. It is true they are both transparent, but they affect the passage of light in different ways. In physics we call that the difference of *refractivity*. For that reason, too, you see no particular colour, but only differences between light and dark.—But now we will consider the air from another point of view. In your lessons in physics you have learnt something about the pressure of the atmosphere and about the barometer; let us take up that now. What is a barometer?

P. A tube full of mercury, closed at the top and open below.

M. Yes, that is pretty correct. I have here a glass tube which can be closed above by a glass stop-cock. At the bottom is a narrow rubber tube, attached by its other end to a second tube which is open (Fig. 40). I open the stop-cock and pour mercury into the other tube, till the rubber tube is quite full and the glass tubes are half filled with mercury. I fix each tube vertically in a retort-stand; now, what is the level of the mercury?



FIG. 40.

P. It should stand at the same height in both legs, and so it does.

M. And now, when I raise the plain tube?

P. The mercury will rise on the other side too. Take care; it's running through the stop-cock.

M. I will shut it, then. Now I will lower the other tube again. But the mercury doesn't follow down; it remains close up to the top. Why?

P. Because the top is shut. No air can enter,

M. What has air to do with the level of the mercury?

P. I suppose it has something to do with the pressure of the atmosphere. Wait, let me think. Yes, air can press on the mercury in the open tube, but not in the closed one.

M. Quite right. But now the mercury begins to sink below the stop-cock. That isn't because the top leaks, for when I raise the other tube the mercury rises again to the stop-cock; and when I lower it the mercury falls again. What is the reason of that?

P. The pressure of the air can't keep the mercury up any longer.

M. That is so. If I raise the open tube the mercury rises in the other one, and when I lower it, it falls. Now we will take some measurements. I place both tubes close together and measure how much higher one column is than the other. It is 75 centimeters. If I now move the plain tube up or down the difference is always 75 centimeters. The pressure of the atmosphere is therefore 75 centimeters of mercury.

P. Yes, that is the height of the barometer. Is that the same as 30 inches?

M. Yes, 30 inches is nearly equal to 76 centimeters. But the pressure of the atmosphere is a pressure, and 75 centimeters is a length. How can you express a pressure in units of length?

P. The pressure of a liquid depends on its height.

M. Doesn't it depend on the width of the column of liquid?

P. No, I learned that it depends only on its height.

M. Yes, for any one liquid. But for different liquids the pressure depends on the density too. Mercury is $13\frac{1}{2}$ times as heavy as water, and so for an equal height

it presses $13\frac{1}{2}$ times as strongly. If you wish to get the same pressure with water as with mercury—

P. The height should be $13\frac{1}{2}$ times less.

M. That's the wrong way round. Think in words.

P. Mercury is $13\frac{1}{2}$ times as heavy as water, and so it presses $13\frac{1}{2}$ times stronger, or water presses $13\frac{1}{2}$ times less than mercury—yes, now I see, the column of water must be $13\frac{1}{2}$ times the height of the mercury.

M. That is right now. What would be the height of a water barometer then?

P. $13\frac{1}{2}$ times 75 centimeters is $1012\frac{1}{2}$.

M. Yes, more than 10 meters. Now can you remember whether the pressure of the atmosphere always remains the same?

P. No, it changes; in fine weather the barometer stands high, and when it rains it stands low.

M. Yes, a high pressure often means fine weather, and *vice versa*; but this isn't always the case, because the atmospheric pressure is affected by many different conditions; however, we won't discuss that just now. You know that the normal height of the barometer is 30 inches, which is practically the same as 76 cms., and that pressure is used as a standard and is called an atmosphere. Can you give the meaning of the word atmosphere?

P. Yes, air.

M. The derivation of the word means a sphere or ball of air. It refers to the pressure of the atmosphere. In physics the pressure is usually measured in centimeters of mercury. Now pay attention to this: 1 atm. = 76 cms. mercury; and 1 cm. mercury = $\frac{1}{76}$ atm. But to-day the pressure of the atmosphere is only 75 cms., that is $\frac{75}{76}$, or 0.987 atm. When I open the tap and let air in after I have raised the other tube, I take in a definite quantity

of air, and I know that, like all the air in this room, it exerts a pressure of 75 cms. of mercury. I level the mercury so that it stands exactly at the mark 100. That means that the tube contains exactly 100 cubic centimeters of air. Now I close the tap again, so that this quantity of air can alter its volume only when the level of the mercury is altered. Now the apparatus is ready for the experiment.

P. What are you going to do?

M. I wish to show you how the volume of the air changes when the pressure is changed. First I will lower the other tube; what do you see?

P. The mercury in the tube with the stop cock falls, but much less.

M. Now we will measure the volume of the air, and the pressure. I can read off the volume from the division on the tube; it is 120 cc. To find the pressure I must measure the distance between the two mercury columns; it is 12.5 cms. What is the pressure of the air now?

P. 12.5 cms. of mercury.

M. Wrong.

P. You said it yourself.

M. I said that the difference was 12.5 cms. In which tube does the mercury stand higher?

P. In the tube with the tap where the air is contained. Yes, the pressure must be less there.

M. Less than what?

P. Than it was to begin with.

M. Quite right. What was it to begin with?

P. I don't know.

M. Yes, you do. Just think! What did I tell you at the beginning of the experiment? What was the pressure of the air when I turned the stop cock?

P. Oh, now I remember, it was the pressure of the atmosphere, 75 cms.

M. And what is it now?

P. 12.5 cms. less, that is 62.5 cms. Is that right now?

M. Yes. Let us set it several times and measure the volume and the pressure of the air. We will make a table.

	Pressure.	Volume.
75	cms. mercury	100 ccs.
62.5	" "	120 "
60	" "	150 "
37.5	" "	200 "
25	" "	300 "

P. What is the use of that?

M. I want to show you *how to discover a law of nature*. We have two quantities, pressure and volume, which change with each other; whenever we give one some definite value, the other must also have a definite value which we cannot control.

P. But the volume depends only on the pressure; I don't see how the pressure depends on the volume. To get a definite volume we must alter the pressure.

M. That depends on the apparatus we are using. If you were closing the mouth of an empty bicycle pump—I mean one filled with air—and then press in the piston, you alter the volume of the air, and you can easily feel that the pressure rises, because it is more difficult to push in the piston.

P. Yes, I see that.

M. Well, then, you see from the table that the greater the pressure the smaller the volume. If we call the pressure p and the volume v we know that for each value of p there is a definite value of v .

P. What is the law for this?

M. It should make it possible to calculate for each p the corresponding v , and *vice versa*.

P. How can that be done?

M. By finding a method of calculating, or, as it is called, a formula, by means of which the one value can be calculated from the other.

P. I don't understand.

M. Suppose you have 10 apples; some in your pocket, the others in your hand. If we call t the number of apples in your pocket and h those in your hand, if you know h you can calculate t , and if you know t you can calculate h . How is this possible?

P. Because I know that the sum of both is 10.

M. So the sum of t and h is equal to 10, and the formula is

$$t + h = 10.$$

From this formula you can calculate t if h is given, or h if you know t .

P. That is very nicely put. But when I come to think of it it is quite unnecessary, because I know it without the formula.

M. You only think so because the formula is so simple and the process so common. But perhaps we can bring our measurements of the pressure and volume of the air into a similar simple formula.

P. Let me try. $75 + 100 = 157$, $62.5 + 120 = 182.5$, $60 + 150 = 210$. No, that won't do, the sum always gets bigger.

M. So the addition formula doesn't work. You might have seen that at first. For you can only add similar quantities, like apples to apples, but not different quantities like pressures and volumes.

P. What sort of formula can it possibly be?

M. If p grows larger, v grows smaller. What combination of p and v has this property?

P. A great many, no doubt.

M. Of course, but not many simple ones. Try to find the simplest possible one.

P. Perhaps the *product*? If one factor becomes larger the other must grow smaller to get the same product.

M. Try if that works.

P. $75 \times 100 = 7500$, $62.5 \times 120 = 7500$, $50 \times 150 = 7500$, $37.5 \times 200 = 7500$, $25 \times 300 = 7500$. Upon my word it's right!

M. Then write the formula.

P. $p \times v = 7500$.

M. Right. Now you have found the law which connects the pressure and volume of the air with each other, or makes them dependent upon each other.

P. I should never have found that out without your help.

M. I quite agree.

P. Tell me, did you find it out by yourself?

M. No. An English physicist named Boyle discovered it nearly two hundred and fifty years ago, and it goes by the name of *Boyle's law*. But we haven't quite grasped the law yet. Supposing the pressures had not been given in centimeters of mercury, but in atmospheres, all the values of p would have been 76 times less. Then the product $p \times v$ would not have been equal to 7500, but $7500/76 = 98.7$, and the formula would have been $p \times v = 98.7$.

P. I see that.

M. Further, if I had not had 100 cc. of air, but only
80—

P. Then the product would have been $75 \times 80 = 6000$.

M. Yes, the first one would be. But what about the others?

P. That can't be told beforehand.

M. Oh, yes, it could; only think. I had taken $\frac{80}{100}$ or $\frac{4}{5}$ of the original quantity of air. Whatever I do with the air, this quantity always remains $\frac{4}{5}$ of the original. And therefore its volume remains under all circumstances $\frac{4}{5}$ of its original volume. Hence all the figures for v would be decreased in the same proportion.

P. Wouldn't the values of p be also proportionately decreased?

M. No. The pressure is equally distributed through the whole quantity of air, and so it doesn't matter whether you take a larger or a smaller fraction of it. The 100 c.c. with which the experiment was made were, of course, only an arbitrary amount of the whole of the air in the room, which had everywhere the pressure of 75 cms.

P. Why do the pressures behave differently from the volumes?

M. As I have often said to you in such cases you mustn't ask why, but notice that certain quantities behave in one way and others in another. Temperatures behave like pressures. For instance, if a mass of water has a definite temperature every part of the mass has the same temperature whether it is large or small.

P. But surely a quantity of water can have different temperatures at different places

M. Quite true, but I was speaking of masses which have the same temperature all through. You see the similarity here between temperature and pressure. If they have different values at different parts of a continuous mass they don't remain in that condition, but become

equal. But we must go back to our experiments. You have seen there is something arbitrary about the number 7500, since it depends on the quantity of air taken and on the units in which the pressure was measured. We must give our formula such a form as not to contain any arbitrary units. Hence we write Boyle's law thus:

$$pv = C.$$

P. What does C mean?

M. It means that the product pv has a definite value C , which remains unchanged as long as only the values of p and v change. For this reason p and v are called variables, while C is a constant; that is, an invariable, or an unchangeable number.

P. But C can have different values too.

M. Only when you change the quantity of air taken. You have already seen that the product pv increases or diminishes its value in proportion to the quantity taken. If you call q the quantity, you can write $C = qK$, where K is another constant which is no longer dependent on the quantity q . Place this value of C in the equation and it becomes

$$pv = qK \quad \text{or} \quad \frac{pv}{q} = K.$$

P. What's the use of this formula?

M. It makes it possible to apply the law to any quantities of gas. If the amount in cubic centimeters is measured at 75 cm. pressure, our former constant $C = 7500$ would be written: $7500 = 100K$ or $K = 75$. If the number 75 be introduced into the last equation, then

$$\frac{pv}{q} = 75.$$

And this equation holds for all experiments with any quantity of air you like.

P. I should like to see that.

M. We will make an experiment. I shut off 60 c.c. of air, at atmospheric pressure, lower the other tube till the volume of the air is 100 c.c. What is the pressure now?

P. How can I tell?

M. You ought to be able to tell; it follows from the formula. You have only to introduce the values in order to calculate p . You know the volume $v=100$ and the quantity $q=60$.

P. $\frac{p \times 100}{60} = 75$, so $p=45$; the pressure is 45 cms.

M. Now, how do I get the pressure 45 cms.?

P. Stop; I can calculate that. The pressure of the atmosphere is 75 cms., and $75-45=30$, so the mercury in the open tube must stand 30 cms. below its level in the other. Let me measure it. It agrees exactly.

M. Are you surprised?

P. Yes; it is almost like magic.

M. What is?

P. That you can tell such a thing beforehand.

M. That is the use of laws of nature to enable us to foretell what will happen in the future. Only think of the predictions of the eclipses of the sun and moon.

P. Yes, I've taken it all in, but I can't say that I'm accustomed to it yet.

M. That is quite to be expected; but we shall often have to do with similar things, and you will soon become familiar with such ideas.

24. CONTINUITY AND EXACTNESS.

M. Have you understood all I told you about Boyle's law?

P. Yes, I understood all that you said. But I couldn't understand a great deal of what you didn't say.

M. Well, then, ask questions.

P. Yesterday we found the pressures corresponding to five or six different volumes. And you got out the formula $pv=7500$, which fitted these few cases, and then you used them for quite different cases. How did you do that?

M. It's a very sensible question, and I will try to make it clear to you. When you blow several times into a toy trumpet, you always hear the same tone; you will expect always to hear the same tone in future whenever you blow the trumpet.

P. Of course.

M. It is much the same with the formula. Whenever you multiplied pressure and volume together the product was 7500, and hence I had the right to expect that it would always be the same. You may remember that our expectation was not disappointed. We tested the formula, and found it held.

P. Oh! I didn't think it was as simple as that.

M. Nor is it. It is an instance of a very important law, one which is so general and accepted that we always use it.

P. A general law! I don't know of any in this case.

M. Certainly you do, because you constantly use it. The fact is that you are not in the habit of expressing

it in the form of a law. It is the law of *persistence of natural phenomena*.

P. How is the law expressed, then?

M. *If an event takes place under definite conditions it will always take place in future if the conditions are the same.*

P. But that goes without saying.

M. People always say that of things they haven't thought about. You had just put a question which was answered by the law.

P. Yes, but that was a case that was new to me.

M. It was only a new application of the general law; it was no new law. You see at once how very important it is to express definitely such self-evident laws. If you had known how to express this law before, you could have answered your own question.

P. So I will in future.—But what we have just been talking about wasn't all that I wanted to know. Of course, I believe that if we were repeating exactly the same experiment with the same volumes, we should get the same pressures. But there are many other pressures and volumes between those that we didn't measure—How can we know that the formula will suit these, for the conditions are no longer the same?

M. That is a very good question. It is also answered by a law of nature.

P. Another!

M. You are getting tired of laws of nature, aren't you? Don't be frightened; it is another self-evident one.

P. All that I mean is that we will soon have so many that there won't be another left to be discovered.

M. So much the better.

P. So much the better?

M. Laws of nature tell us what we have to expect under definite conditions. Now no law includes all such conditions, but only one or a few. Hence, in order to know exactly what will be the final result, we must know the laws for all possible conditions, so that all uncertainty disappears and only one thing is possible. Then, that particular result will really take place.

P. Oh! so what you really meant was that there should be no doubt of the result.

M. That wasn't quite your view, was it? The general law of which I spoke is one that relates to the *continuity of natural phenomena*.

P. Explain that.

M. We have just seen that we can express natural laws in the form:—if this is the case the other will follow. Now the “this” is often not one single definite thing, but something capable of different degrees, shades, and magnitudes, and other things depending on these. If we alter one of these continuously, that means, so that there is never a sudden change in its value, the other also alters continuously, and its value makes no sudden change, either.

P. I think that I can remember a Latin proverb about that. *Natura non facit saltus* Nature makes no jumps.

M. Yes, but it's only a half-truth. Nature does make jumps; but then all magnitudes which are connected with each other make jumps at the same time.

P. I can't think of an example.

M. Just think of the transition from ice to water.

When the solid changes to the liquid its physical state changes suddenly, and at the same time its volume suddenly becomes one-eleventh smaller, and its power of refracting light, its electrical properties, and countless other things suddenly change their value too.

P. Do *all* its properties change at the same time?

M. Nearly all; mass and weight, however, remain unchanged.

P. I still don't see what all this has to do with my question.

M. You asked how it was possible from a few values of pressure and volume for which you found the product constant, to assume all intermediate values to be the same. But it can be deduced from the law of continuity. For if the product is the same for any two values of pressure which lie somewhat near each other, then it must also be the same for the pressures which lie between these two, unless one of the factors suddenly alters its value. But the law of continuity excludes such a possibility.

P. I don't quite understand that.

M. Think of the example of the toy trumpet. If you blow gently the first time and hard the second, and the tone is always the same height, you might conclude that if you were to blow only fairly hard, you would still hear the same tone.

P. Yes, of course.

M. You have just applied the law of continuity.

P. Oh, is it as simple as all that?

M. It is; the difficulty isn't in understanding the law, but in applying it to unfamiliar cases. But now we will go on with Boyle's law. Up to the present we have only tested it for pressures which lie below that of the atmos-

phere. What do you think—will it hold for higher pressures?

P. I don't know any reason either for or against.

M. Yes, you know one in favour of it: the law of continuity. Try to apply it.

P. At pressures which are a little higher than one atmosphere the product pv will still be the same.

M. Quite right.

P. But how far can I go?

M. You can only tell by experiment. We will lift up the open tube as far as we can. Now the volume has contracted to 40 c.c., and the difference of the mercury level is more than one metre. I will use a second metre rule; now I find $112\frac{1}{2}$ cms. Does that agree?

P. $112\frac{1}{2} \times 40 = 4500$. No, the product is much too small.

M. Now just think.

P. Of course I forgot the pressure of the atmosphere. But I can't subtract $112\frac{1}{2}$ from 75

M. Why should you?

P. Because—no, how stupid I was; the mercury is now pressing on the same side as the atmosphere, so I must add them and not subtract: $112\frac{1}{2} + 75 = 187\frac{1}{2}$, and $187\frac{1}{2} \times 40 = 7500$. It's quite correct.

M. What conclusion would you draw for pressures which lie between that and one atmosphere?

P. The product will agree for those too, according to the law of continuity.

M. You needn't laugh, it's quite right. To convince yourself you may make some measurements with the apparatus.

P. That's capital; thank you very much.

M. Only take care that you don't spill any mercury;

you had better take the lid of a large pasteboard box and work with your apparatus on it.

M. Well, have your measurements been successful?

P. Not very. The product of pressure and volume didn't always come to 7500; it was sometimes a little more, and sometimes a little less.

M. That is what you might have expected.

P. Then is Boyle's law not exact?

M. The law is, but not your measurements. How accurately did you read the levels?

P. Oh, it wasn't easy to hold the rule upright and to read the level of the mercury.

M. Look here, you can't have been a whole centimetre wrong, though you may have made a mistake of some millimetres. Look at my last result, where the volume was 40 c.c. and the pressure $187\frac{1}{2}$ cms. If I had read $\frac{1}{2}$ a cm. too much (which was quite possible because I had to lengthen the rule) I should have got $188 \times 40 = 7520$ instead of 7500. If I had read $\frac{1}{2}$ cm. too little the product could have been 7480. That shows the influence of *experimental error* on the result.

P. Yes, my numbers were something like these.

M. Moreover, you may have made a mistake in measuring your volume. The tube is graduated in cubic centimetres and tenths, and you may have made the mistake of a tenth. If you had read 40.1 instead of 40 it would have given $187\frac{1}{2} \times 40.1 = 7518.75$, again an erroneous result. If you had also read the pressure wrongly, say 188 cms., the product would have been 7538.8.

P. Well, how can you know which is the right number?

M. You can never know, for every experiment contains an error.

P. Even when you measure very accurately?

M. Then you will make your error smaller, but it will never disappear.

P. But is nothing ever measured accurately?

M. No magnitude is ever measured so accurately that there is no error at all. There are only measurements of greater or lesser accuracy.

P. But what can be done if the numbers are as different as those I got? What value should be taken as the correct one?

M. You can't state the correct value, but you can state one which is *probably* the nearest to the correct one.

P. How can that be done?

M. Think for a minute. You may have made errors which would have made the result too large, as well a too small, and so the correct value will lie somewhere in the middle, between the largest and the smallest values which you found.

P. I see that.

M. Then you must take the mean value of all your observations. That can be done by adding all the observed values together, and dividing by the number of observations. The quotient is called the mean value, and it is the most probable one.

P. Please let me try so that I may understand it. I found for the product pv the numbers 7520, 7475, 7492, 7533, 7506, 7491.

M. There are six values; add them and divide by six.

P. 7520

7475

7492

7533

7506

7491

$$45017; \frac{45017}{6} = 7502.833 \dots \text{How many decimals}$$

shall I write?

M. None at all.

P. But then I shall make a mistake.

M. You know that all your measurements contain an error. If you examine your numbers you will see that even the tens don't agree, and the units must be quite uncertain. Of your mean value 7502.833... the 0 in the tens place is perhaps right, but the two units are quite uncertain, because they would have come out differently if you had made another measurement.

P. So I will.—It comes out 7511.

M. Do the calculation with the seven values now; what do you find?

$$P. \frac{52528}{7} = 7504.$$

M. You see you have got two more units. It would lead to error if you were to write units or decimals. The usual plan is simply to write 0 for such uncertain places to show that you can make no statement about them. Do that; what is your mean value?

P. 7500.

M. Quite right.—Now let us go back to the question whether Boyle's law holds for any pressure. The

answer is that it has been shown to be nearly correct for the smallest pressures which can be measured. On the other hand, at higher pressures there are deviations, small indeed at 10 atmospheres, considerable at 100, and very great at 1000.

P. Where do these deviations begin?

M. The answer depends upon the exactness of the measurements. The more exactly the pressures and volumes are measured, the smaller are the pressures at which the first deviations can be detected.

P. So Boyle's law is not exact.

M. No; that can't be said of any law of nature. But so far as its application is concerned, it is exact enough, because the errors of our measurements will always be much greater than the deviations from the law.

25. THE EXPANSION OF AIR BY HEAT.

M. Do you quite understand Boyle's law now?

P. I think I do, but there is something I am not clear about. You once told me that air expands when it is heated. But then the same quantity of air at the same pressure would have different volumes; it would have a bigger one if it was warm and a smaller one if it was cold.

M. You are quite right. Boyle's law holds only for an unchanging temperature.

P. What temperature?

M. For any temperature, but it must remain constant. Our experiments were carried out at the temperature of

the room, which was about 18° . If it had changed much while we were making them our results would not have been concordant.

P. Does that mean that Boyle's law is not worth much?

M. It has lost none of its value, only you have learnt one of the conditions which must be fulfilled when it is applied.

P. If the temperature doesn't remain the same, what can we do?

M. Then we try to find out a law which will allow for its influence.

P. How can that be done?

M. If we know how much the volume of a given quantity of gas alters when the temperature is changed by a known amount, we can apply a correction to our measurements, so that the result comes out as if it had been obtained at some one definite temperature.

P. I have a sort of general idea, but am not clear about it yet.

M. You will soon understand it. Here is a narrow glass tube about 2 mms. wide, about half a metre long, closed at one end, and containing at about the middle a drop of mercury, which shuts off a definite quantity of air. If I warm this air with my hand, the drop moves forward, and it goes back again when the air cools. Thus you can see and measure the expansion of the air by heat.

P. It is just like a thermometer.

M. Yes, an air-thermometer. Now I place the tube in melted ice and mark where the drop stands with a small india-rubber ring.

P. Where did you get it?

M. I cut it off a piece of rubber tube with a pair of

scissors. Now I measure the length of the column of

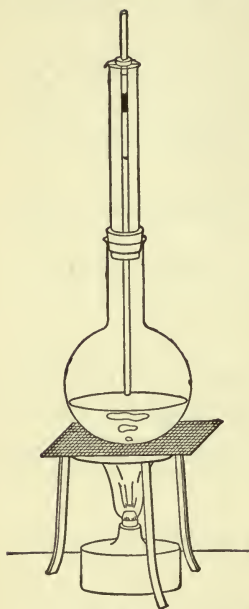


FIG. 41.

air which is cooled to 0° in the ice; its length is 273 mms. Now I will heat the same quantity of air to 100° , the boiling-point of water. To do this I fit a flask with a somewhat wide glass tube by means of a cork, and boil the water in the flask (Fig. 41). When I place the tube in the steam the drop moves up considerably.

P. How can you make a mark on it without burning your fingers?

M. I push down the second india-rubber ring with a rod to the right place. Now it is done. I take the tube out and measure the length of the column of air. The second ring stands at 373 mms.

P. That is exactly 100 mms. more; a millimetre for each degree. How does that come out so exactly?

M. I knew beforehand that 273 volumes of air when heated from the freezing- to the boiling-point of water would expand exactly 100 volumes, and I enclosed exactly the right quantity of air to begin with.

P. Did you do that at 0° or 100° ?

M. No; I looked at the thermometer in the room and saw that it stood at 18° . As 273 divisions at 0° expand, one division for each degree, I knew they would occupy at 18° $273 + 18 = 291$ divisions. So that I placed the drop of mercury 291 mms. from the end of the tube.

P. How did you do that? The drop doesn't move when I tilt the tube.

M. That is very simple; it doesn't move because the air can't pass the drop. I pushed a horsehair into the tube through the drop and it moves quite easily now. Look!

P. That's neat. But how did the air pass? Oh, I see; the mercury doesn't quite touch the glass where the hair is.

M. Yes; what is called surface-tension makes the mercury curved, and the air can not pass except through the narrow groove between the glass and the hair. But we will go back to our experiment. We will make a diagram (Fig. 42). The horizontal line stands for a thermometer. At the mark 0 water freezes, at 100 it boils.* Each millimetre stands for one degree.

P. I understand that.

M. Now we will draw horizontal lines each of which represents the volume of the air in our experiment. We will make the horizontal line at 0, 273 mms. long; and at 100; 373 mms. We join the two end-points by a straight line.

P. What is the use of the figure?

M. It makes it possible to find the volume of the air for any intermediate temperature. Pick out the point 18° on the thermometer-line and measure how long the horizontal line is.

P. It is 290—no, 291 mms. long. I have just had this number—yes, it was the place where you set the mercury with the horsehair.

M. Yes, that is the volume of the air at 18° .

P. How does it happen that the right number comes?

* Fig. 42 is reduced to a quarter of its right size.

M. That is very simple; for each degree the length of the air-line increases by 1 mm., and so the ends of all these lines lie in a straight line.

P. Yes, I understand that. I see, too, that I can find

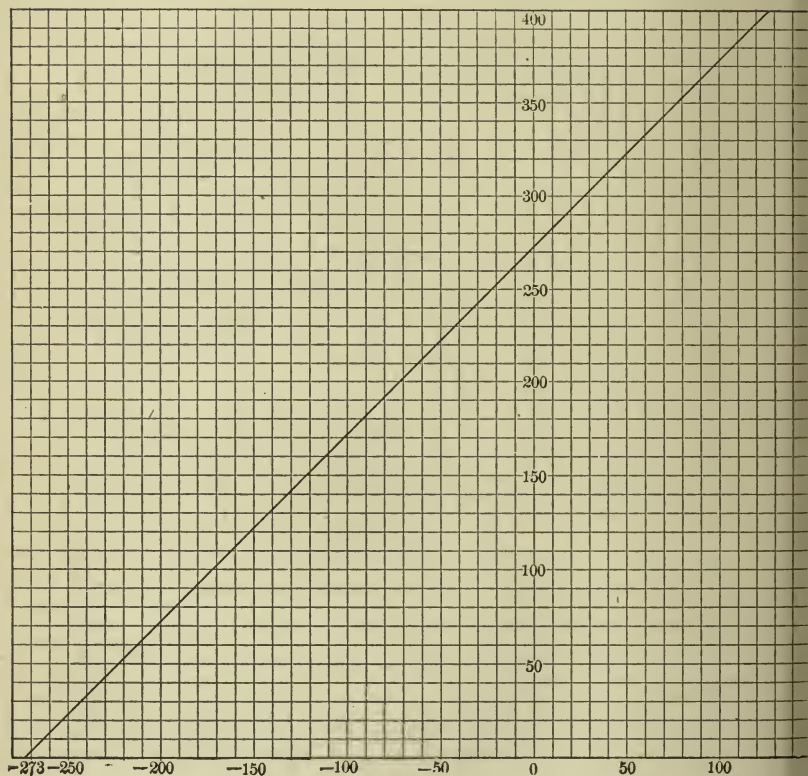


FIG. 42.

out what the volume of the air will become when it has exactly the volume 273 divisions at 0° . But—

M. Well?

P. I was going to ask something stupid. If I know it for 273 divisions I can calculate it for any other number by simple proportion.

M. Quite right. When 273 divisions measured at 0° increase one division for each degree, one division will increase by $1/273$, and for any number of degrees, which may be called t , by $\frac{t}{273}$ divisions. You can draw this more easily if you use paper ruled in millimetres. There is a net of lines on the paper which stand exactly 1 millimetre apart, and you do not need to measure, but you can count the numbers directly.

P. But I must count the lines.

M. That is very easy; for every fifth and tenth line is a little broader, and you need only write 10, 20, 30, etc., on these lines.

P. Yes, that works very well.

M. Now tell me: what would be the effect of cooling the gas below 0° ?

P. I think that its volume would decrease by $1/273$ for each degree.

M. Quite right. In our drawing you need only produce the line downwards towards the left in order to represent volumes below 0° .

P. But I don't see what that means; the line gets nearer and nearer the thermometer-line and finally touches it. That must mean that the volume of the gas becomes nothing, and if I produce it further, less than nothing.

M. Quite right. At what temperature does that happen?

P. About -273° .

M. Yes; if air loses $\frac{1}{273}$ of its volume for each degree, at 273° below zero nothing is left.

P. Is that really the case?

M. I don't know, for the temperature -273° has never been reached.

P. Why not?

M. It hasn't been found possible. The lowest temperature ever obtained is about -260° , and from the trouble which it has cost to lower the temperature, we must conclude that it will be long before any attempt to lower the temperature 10° more will be successful.

P. Has the air at -260° really the small volume that is shown on the diagram?

M. The volume is still smaller, but the reason is that at -190° air is no longer a gas, but condenses to a liquid.

P. Oh, then this part of the diagram has no meaning.

M. Yes it has. There are other gases, for example, helium, which behave exactly as the diagram would indicate, at the lowest temperatures. Helium has never been liquefied; at lower temperatures it would be, no doubt; but we can imagine a gas that wouldn't and then it would behave as is shown in the diagram.

P. Does the diagram apply to all gases?

M. Yes, all gases behave exactly like air, and alter their volume by $\frac{1}{273}$ of the volume which they occupy at 0° , for each change of one degree. Here we again have a general law of nature, which makes it possible to predict the behaviour of very different substances. You can say beforehand that if any substance is a gas, it will expand by $\frac{1}{273}$ of its volume for each degree.

P. That is very convenient.

M. You can see that all gases point to the temperature -273° as a limiting temperature. It is probable that it

would be impossible to obtain lower temperatures than -273° . This would therefore be the lowest possible temperature; you may remember we spoke of this before; and if we mark the position of the mercury in the thermometer at the melting-point of ice, with the number 273° , and the boiling-point of water with 373° , we should probably never be obliged to calculate with negative temperatures. We therefore call the temperature -273° the absolute zero, and the temperatures counted upwards from it are called absolute temperatures.

P What is the good of that?

M. It is very useful in many respects; chiefly in the theory of heat, and the time hasn't come to explain that to you. But I will tell you one thing. If the melting-point of ice is made 273° , and the boiling-point of water 373° , these numbers have the same ratio to each other as the volumes of air or of any other gas at these temperatures.

P. Why is that?

M. You only need to look at your diagram.

P. Oh, I understand. The diagram has been made from these numbers.

M. So the volumes of gases are proportional to their absolute temperatures.

P. That's very neat. I didn't think I could have learned so much from a simple drawing.

M. Do you see why? It is because in a diagram everything is before your eyes, whereas in words or calculations we can only discuss single points. You must always try to represent general relations, or laws of nature by means of diagrams.

P. I'd do it if I only knew how.

M. We shall have other examples.

P. Please let me put one question before you stop. You have been speaking again as if temperature was the only reason why the volume of air alters, but I know that pressure changes it too. What happens when both change at the same time?

M. That is a very good question. You want to know how to calculate the volume of a gas when both its temperature and pressure change?

P. Yes.

M. Then calculate first the change that would take place if only the pressure were altered without change of temperature, and then the change which would be produced in the resulting volume by change of temperature at constant pressure.

P. Why must I first calculate the change of pressure?

M. You might just as well calculate the change of temperature first.

P. Should I get the same result?

M. Of course. The volume of the gas depends only on the temperature and the pressure, and it is all one in which order they are taken.

P. That looks right, but I don't feel quite sure about it.

M. Let us take an example. Suppose we have 350 ccs. of air at 18° , and that 74.8 cm. is the height of the barometer, and that we wish to know what the volume will be at 0° and 76.0 cms. That is the standard temperature and pressure for measuring gases; they are called normal temperature and pressure. Let us suppose first that according to Boyle's law the volume varies inversely as the pressure. Let us call the unknown volume at 76 cms. y , then $y:350=74.8:76.0$.

P. Then $y=344$.

M. Furthermore, the volume at 18° is to the volume at 0° as $273+18=291$ to 273 . If you call the volume at 0° x , you have the proportion—

P. $x:344=273:291$, therefore $x=323$.

M. Quite right. Now you can reduce the volume 350 ccs. first to 0° , and then to 76 cms. pressure, and convince yourself that you get the same answer.

P. We have been talking so long about air that I have almost forgotten that these are supposed to be lessons in chemistry.

M. What you have learnt holds for all gases. If you have two equal volumes of any two gases at equal temperature and pressure, their volumes always remain equal, however you alter simultaneously the temperature and pressure of the gases.

P. It is quite different from liquids, for water expands differently from mercury.

M. Yes, gases show no peculiarities; they all behave in the same way. You will see later that the behaviour of gases is identical in many respects whatever their chemical differences.

P. Are all gases colourless?

M. No, I have told you already that chlorine is greenish, and iodine gas violet. But I must tell you that the conformity is confined to the gaseous state. As soon as a gas condenses to a liquid the differences appear again, for one gas is more easily condensed than another. The same is the case when gases dissolve in water or other liquids. But as long as the substances are in the state of gas, the uniformity of their external properties is maintained.

P. I'm glad you have answered my question. For now I have learnt without knowing it that what you

have taught me about air applies to all other gases. Do vapours, like steam, obey the same laws?

M. Certainly there is no difference.

26. THE WATER IN THE AIR.

M. So far you have learnt about two of the constituents of air, oxygen and nitrogen, but these are not all; there are others, among which water in the state of vapour is important.

P. Yes, I wanted to ask you about that. The pressure of the air is one atmosphere, and at that pressure water boils at 100° . How does it happen that water-vapour can be present in air when it is much colder than 100° ? Why doesn't all the water-vapour condense to liquid water?

M. I am very glad you are taking such pains to learn, for I have given you a hint how to answer that question. It happens that when water evaporates only the pressure of its own vapour counts, and not the pressure of other gases and vapours which may be present at the same time.

P. Please explain that to me.

M. Remember what I told you before about the behaviour of water in a vacuum (page 176); it will evaporate until the space is filled with vapour of a definite density. Now if any other gas is present in the same volume, for example, air or hydrogen, the water-vapour will do exactly the same thing—it will be formed until it has filled the space. Its pressure will be added to the pressures which the other gases exert, and the final pressure will be the sum of all.

Only the evaporation is somewhat slower, because the vapour requires time to spread or diffuse throughout the other gases.

P. I think I understand, but I should like to see it.

M. First of all, you can easily convince yourself that ordinary air really contains water in the state of vapour. You know that this water deposits upon cold objects in the form of dew, and that rain falls because the water-vapour of the air changes into liquid water when it is cooled.

P. So water-vapour can be removed from air by cooling it?

M. Quite easily. I close the neck of a small flask with a cork, through which pass an entry and exit tube (Fig. 43), and make a freezing-mixture with powdered ice and salt, in the proportion of 3 to 1, and surround the flask with it. Then I only need to draw air from the room through the flask for some time in order to collect a considerable quantity of water in the form of ice in the flask. If I let the flask warm up, of course I get water.

P. But how can I make a stream of air pass through the flask? It is tiresome to suck so long.

M. We will use our gas-holder for it (Fig. 28, page 149). If we place the empty bottle on the floor, and connect the other with it by means of an india-rubber tube, when the water runs into the lower bottle it sucks air into the upper one. We can regulate the rate with the clip. And if we want to suck more air through, we have only to reverse the bottles, and connect the upper one with the under one by the tube.

P. That's capital. It didn't occur to me that you could suck with it as well as blow.

M. Now the experiment has been going long enough; you see a quantity of frost has condensed in the flask.

P. Is cooling the air the only way to take water out of it?

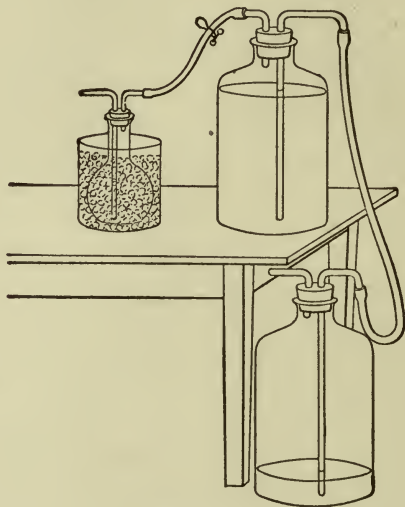


FIG. 43.

M. No, it can be done in other ways. There are many substances which combine so easily with water that we only need to lead moist air over them to remove the moisture. Caustic soda, which you have already seen, is such a substance (page 70); another is a salt named chloride of calcium, which is made in large quantities as a by-product in chemical works. When it is dried or fused it takes water so quickly from the air that a piece left in an open dish changes in half an hour into a liquid drop. Air and other gases can be very easily dried by its help.

P. How?

M. The salt is placed in a specially shaped tube (Fig. 44) and the gases that we wish to dry are led through it. If you cannot blow such tubes for yourself, you need only close a wide tube at both ends, with perforated corks having narrow tubes through them; only don't

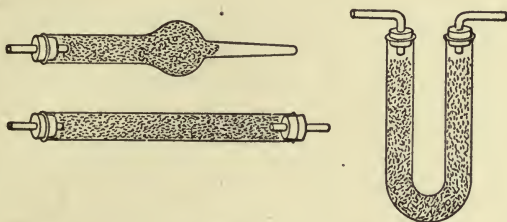


FIG. 44.

forget to close the end of the tube with cotton-wool in order that particles of dust from the salt may not be carried along by the stream of air. If you weigh such a tube exactly, and then pass a measured quantity of air through it and weigh it again, you can find out how much water was in the air.

P. I shall try that.

M. You will not find much unless you pass a couple of dozen litres through it.

P. How much water is there in the air?

M. It varies greatly. It depends on the temperature as well as on the source of the air. Do you remember what I have just told you about the evaporation of water in the air (see page 218).

P. Yes, exactly as much evaporates as if there were no air present in the space.

M. Quite right. You know then that the pressure of the vapour, and consequently the amount in a given volume, will be greater the higher the temperature. Here

is a table which shows you how many grams of water-vapour are present in a litre of air when it stands in contact with liquid water, or, as we say, when it is saturated with water-vapour. A litre of saturated air contains

At 0°.....	0.0049-gram	water-vapour
“ 5°.....	0.0068	“ “
“ 10°.....	0.0094	“ “
“ 15°.....	0.0127	“ “
“ 20°.....	0.0171	“ “
“ 25°.....	0.0228	“ “

P. The word saturated is the same that you use for solutions.

M. It is really the same thing, for it means that the air cannot take up any more water-vapour.

P. But it can take up less?

M. Certainly, that is also the case with solutions. Ordinary air like what is in the room is almost always unsaturated; it is only saturated when rain or mist is present. The proportion between the amount of water in the air and the quantity required for saturation is called the *hygrometric state* of the air. When air, for example, at 20° contains 0.0140 gram of water per litre its moisture is equal to $\frac{0.0140}{0.0171} = 0.82$, or 82 per cent,

because, according to the table, it could contain 0.0171 gram. Air generally contains about 70 per cent of moisture; if it contains 50 per cent we call it dry, and we call 90 per cent damp.

P. I understand that.

M. Now look at the table again; if the temperature rises 10° the amount of water is nearly doubled. A sample of air which is only half saturated at 20° is almost

completely saturated at 10° , and ordinary air with 70 per cent of moisture, if it is cooled 10° , will part with a good lot of its water in the liquid state. That is the reason of rain.

P. Numbers make such a lot of things clearer than words. But why should rain come and not mist?

M. That depends upon how much water has to be separated. If there is only a little, the very small drop-lets which are formed do not unite to large drops and the result is fog; in other cases rain occurs, but fog and mist always precede rain; we call the fog which occurs in the upper air a cloud.

P. How do you know that clouds are only mist?

M. The tops of mountains are often hidden by clouds, and when you climb them you find the clouds are nothing but mist.

P. Please tell me how it happens that air is not completely saturated with water-vapour. It is always touching water, either the sea or ponds on the land.

M. That depends on its motion. Suppose you had the air saturated in one place, if it moves to a warmer place it will become unsaturated as you can see from the table, or if it moves to a colder place it loses a portion of its water in the form of rain. And when it recovers its original temperature, it is unsaturated again. So whatever happens, when it changes it can only change in one direction, in becoming less saturated.

P. That is far simpler than I thought it was.

27. CARBON.

M. The element carbon is as widely distributed and as important as oxygen, hydrogen, and nitrogen. You already know that ordinary charcoal is one form of that element.

P. I thought you would be speaking of carbon to-day, and so I looked at a piece of charcoal. I noticed one thing; you can see the rings in the charcoal just as in the wood.

M. Yes, you can see the rings which show the number of years of growth, and besides that you can see under a microscope the single cells of which the wood consisted.

P. But surely wood doesn't consist only of carbon?

M. No; it is a compound of carbon, hydrogen, and oxygen. In charcoal-burning as it is called the wood is slowly heated, and carbon alone remains, for the other two elements are expelled. But as carbon melts only at a very high temperature, which is not nearly reached in charcoal-burning, the remaining charcoal retains the form of the cells of which the wood consisted. Moreover, wood charcoal is not pure carbon. You see that when it burns, for ashes always remain, while pure carbon leaves no residue on burning.

P. Is there such a thing as pure carbon?

M. Certainly; ignited lampblack is nearly pure carbon. You know that lampblack is a very fine black powder.

P. You said before that almost all pure substances form crystals, but lampblack doesn't look crystalline.

M. Nor is it. Such substances are called *amorphous*, which means without shape. Lampblack is *amorphous* carbon; so is wood charcoal, only it is *impure*.

P. Is coal carbon, too?

M. No, ordinary coal and its varieties, anthracite, brown coal, and peat, are all chemical compounds which contain a large percentage of carbon; anthracite contains most; peat, least. They all owe their origin to plants. Indeed, in coal the remains of plants are not infrequent; in brown coal they can be seen even more distinctly, and peat sometimes consists almost entirely of stems and roots. These materials, owing to their being buried a long time in the earth, have undergone almost the same changes, as wood undergoes on being carbonized by heat, only the change is a much slower one.

P. Now I begin to see why you told me that carbon was such an important element. All fuel consists of carbon.

M. Quite right. But fuel is used not merely for heating, but for all sorts of other purposes. All machines except those driven by running water, like water-mills, are driven by means of carbon; moreover, in chemical works and in works in which iron and other metals are smelted, the processes are all carried out by help of carbon; indeed, the progress of our civilization may be said to depend on carbon.

P. Why is that? I mean why is carbon required for all such purposes?

M. By the burning of carbon a large amount of work is made available, which generally appears in the form of heat. By help of such work machines are set in motion. Chemical processes are carried on which would not go of their own accord; in short, carbon places at our disposal quantities of energy which we use for all sorts of work.

P. Why, you said the same about oxygen.

M. Energy is only liberated when carbon and oxygen combine with each other, that is, when carbon burns. You see the carbon is as necessary as the oxygen.

P. And because oxygen is a gas, it is everywhere round us, but carbon must be bought because it is a solid.

M. Well done! that is a good remark. What you say is quite right. But you see this gives people the power of putting energy where it is wanted. If carbon were all round us in the form of gas, as air is, you might perhaps be able to set the air on fire, but you couldn't have a fire in a fire-place.

P. They would explode.

M. Quite right. But don't let us speculate; let us think of what actually exists. Carbon is the most important source of energy at the disposal of our industries. Notice this; when carbon is burned, the *products* of its combustion are sent up the chimney as fast as possible, only people try to keep in the heat which is produced at the same time as thoroughly as possible. It is evident then that coal is bought not on account of the carbon it contains, but on account of the energy which it can give out.

P. It never struck me in that way before. But I see that it must be right.

M. You know that a steamer or a locomotive must carry coal with it. Each can go only as far as the coal will permit. If the coal gives out the engine stops. And so there are islands on the ocean, and stations on the coast, where ships can buy more energy in the form of coal.

P. But if I were to row a boat I shouldn't need to burn any coal.

M. You know the answer quite well yourself. Think of what I told you about the use of oxygen in supporting life.

P. Yes, I remember that food does the same as coal. But does food consist of carbon?

M. All food contains carbon, and when it burns it gives up energy, just as when it passes through our bodies. Food consists of compounds of carbon, hydrogen, and oxygen; sometimes it contains nitrogen too.

P. Yes, I remember. Foods that give a disagreeable smell on burning contain nitrogen.

M. Yes. As food is also used for the building up of the body, all substances of which the bodies of animals and plants consist contain carbon. Such substances are called *organic compounds*, because animals and plants are called organisms.

P. Are there many organic compounds?

M. We know more than a hundred thousand, and new ones are being discovered every day.

P. How can any one remember them?

M. No one can, of course; but that doesn't matter; there are dictionaries in which accurate descriptions of all these compounds are to be found.

P. Do other elements form as many compounds?

M. Not by a long way. And so the chemistry of carbon compounds is treated separately from that of the other elements, and called organic chemistry, while the chemistry of other substances is called inorganic chemistry.

P. Isn't that rather an arbitrary division?

M. Not so much as it looks. Carbon compounds have certain general properties which bring them naturally into one group. Moreover, certain simple carbon compounds are treated of under the head of inorganic

chemistry, because carbon occurs in many minerals and rocks.

P. Yes, as coal and peat.

M. No, in other chemical compounds. Marble and chalk contain carbon. But we shall come to that later; in the mean time let us consider the uncombined element. We must now consider a new phenomenon which you ought to learn about. Do you know that the diamond is nothing but carbon?

P. Yes, because it can be burned when it is heated very hot.

M. That is not a sufficient reason, because many other substances can be burned at a high temperature although they are not carbon. Oxygen, you know, unites with most other elements.

P. Yes, but when a diamond burns I have read that nothing is left.

M. That is a better test. We could infer that the oxygen compound or the *oxide* of the element or elements of which the diamond consists is volatile. But carbon is not the only element which leaves no residue in burning. Sulphur and hydrogen give volatile oxides.

P. It must depend then upon what is formed.

M. Quite right, now you are getting nearer it. When carbon burns a gas is evolved which is called carbon dioxide; we have talked about it already (page 68). It can be easily recognized because it gives a white precipitate with lime-water, and makes clear lime-water milky. To remind you, I will make the experiment somewhat differently; here is a fragment of charcoal in a glass tube. Now I will heat the place where it lies and pass air over it from the gas-holder (page 220). The tube is bent so that the end dips under lime-water

in the glass. Now the carbon begins to glow, and you see the lime-water is turning turbid.

P. If I were to heat a diamond instead of charcoal, would it burn and turn the lime-water milky?

M. Yes, it would, only you couldn't make the experiment in an ordinary glass tube, because the diamond would not catch fire at so low a temperature; the tube would melt. Moreover, you would require to use pure oxygen, for the diamond would then burn more easily.

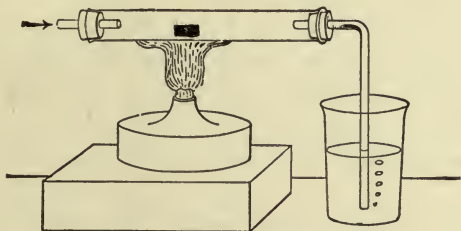


FIG. 45.

P. Yes, I see the proof that the diamond is really carbon.

M. Stop a little; not quite so quick. You would only prove that the diamond contains carbon, but not that it contains nothing but carbon. How could you find out that there are no other elements present?

P. I don't quite understand you.

M. Look here. I shall repeat my former experiment with a piece of wood. It catches fire, too, and the lime-water again turns milky. Yet I cannot say that the wood is carbon, but only that it contains carbon; for it also contains hydrogen and oxygen.

P. Let me think. Now I have it; water must be produced by the burning of the hydrogen. If carbon di-

oxide is the only product, we know that the substance contains only carbon.

M. That is more nearly correct, but not quite. The diamond might be a compound of carbon with less oxygen than is contained in carbon dioxide. Such a compound on burning would give only carbon dioxide, and yet it would not consist of carbon alone.

P. Is there such a compound?

M. Certainly, but it is not a solid hard substance like a diamond, but a gas.

P. Then there's no risk of mistaking it for a diamond?

M. You are trying to evade the point. That is unadvisable, because you will miss an opportunity of learning something.

P. I must say I don't understand the question of the diamond.

M. When carbon burns, 3 parts by weight of carbon always give 11 parts of carbon dioxide, for it combines with 8 parts of oxygen; now with the diamond that is the proportion. If the diamond contained some element besides carbon it would give less carbon dioxide, and indeed the amount would be proportional to the amount of carbon it contains.

P. Then wood must give much less carbon dioxide than charcoal.

M. So it does; 3 parts by weight of wood give at most $4\frac{1}{2}$ parts of carbon dioxide.

P. And no single substance is known which gives more?

M. Not one. But there is another substance which gives exactly the same amount, namely, graphite, of which ordinary lead pencils are made.

P. Then it must be carbon?

M. Yes, we must therefore say that carbon appears in three different forms: charcoal, diamond, graphite.

P. But I don't understand that. How can one and the same substance exist in three different forms, and why do people not make diamonds from charcoal if it contains only carbon?

M. That is a very good question and I will answer you as well as I can. You already know that one and the same substance, for example, water, can exist in different forms. Water, indeed, exists in three, namely, ice, water, and steam.

P. Yes, there are three forms, but carbon, diamond, and graphite are all *solid* bodies. But if all three could be changed into each other by heating or cooling then I would believe it. But they can all exist together at the same temperature.

M. You are quite right. Nevertheless charcoal can really be changed into graphite; it takes place at a very high temperature.

P. Can you show me that?

M. It is not so difficult. The carbon rods used for electric lamps consist of ordinary carbon. The next time the workman puts in new carbons ask him for one of the old ends. You will see that the points have become grey and smooth and shine something like a metal; they have changed into graphite. The carbon threads of an electric glow lamp have undergone the same change owing to the high temperature at which they have been kept. Indeed, they are made of cotton carbonized, and after they have served their purpose they become grey and shining like graphite.

P. Next time a lamp burns out I will ask for it and break it open.

M. Take care that you don't lose the very fine thread.

P. Can diamond also be changed into graphite?

M. Yes, in exactly the same way, by heating it strongly.

P. And can the change be reversed?

M. Graphite can only be changed into ordinary carbon by a roundabout process. It has to be made into compounds, and the carbon separated again from them.

P. I don't quite understand that.

M. I will not try to explain it to you now, since substances must be used which you do not know about. You must be contented in the mean time in believing that it is possible.

P. But how is it with diamonds? Can they be made from charcoal or graphite?

M. That is also possible.

P. Then why aren't diamonds cheap?

M. There is no danger of that, because only minute diamonds can be made, and in very small quantity.

P. But why is that? Charcoal is cheap enough.

M. Yes, that brings us again to our general question. I compared the three states of carbon with the forms of matter. Now carbon is also able to become liquid and gaseous, so that the ordinary forms of matter are known in its case.

P. Liquid and gaseous carbon!

M. Yes, but a very high temperature is necessary—more than 3000° ; however, it can be reached by the electric current. You see then that carbon can exist in the gaseous, liquid, and solid states. Carbon is known not only in three, but in five, different states.

P. So that's how it is. Yes, I see. Just as water can be changed to steam by heating it, so charcoal changes to graphite by heating; no, I don't see yet. When

graphite cools, it doesn't go back to charcoal, but remains as it is.

M. Yes, that is the most difficult side of the question, but I think I can explain it to you. You know that water changes into ice at 0° . Do you remember what I told you about super-cooling (page 164).

P. Yes, that water can be cooled below 0° , and remains liquid if no ice is present.

M. Right. I have here a sealed glass tube containing water into which no ice can enter. I now place the tube in a mixture of ice and water which of course is at 0° , and I can leave it as long as I like; ice will never be formed.

P. That won't do, you must cool it below 0° .

M. Quite right. Now if I add some salt the temperature will fall below 0° . Half a teaspoonful will do; the thermometer shows -4° , and there is no sign of the water freezing.

P. But if you were to leave it for a long time?

M. Nothing would happen. If I were to add more salt so as to lower the temperature to -10° , and were then to shake it violently ice would be formed.

P. Yes, I see that.

M. Now with a diamond, you must think in the same way. The conditions of our experiments are such that the diamond cannot be formed. In order to produce it a very great pressure and a very high temperature are necessary. These conditions are difficult to obtain, and hence it is very difficult to make diamonds.

P. Yes, I can understand that. But why is carbon the only substance which behaves like that?

M. Carbon is not the only substance. You will soon

become acquainted with other substances which also exist in several solid forms.

P. Are such different forms only known in the case of solid substances?

M. For the most part. Such substances are called *allotropic*. Charcoal, diamond, and graphite are allotropic forms of carbon.

P. Now I think I understand it a little. But I want to ask one question: What do these differences depend on—what are they connected with?

M. With the differences in the amount of work or energy in the substances. Just as work is required to change ice into water, or water into steam, so energy is required to change charcoal into diamond; and no second substance takes part in this change in either case.

P. Could we not regard energy as a kind of chemical element which combines with a substance, and gives it different properties?

M. That is one way of looking at it, but energy possesses no weight, and therefore during such allotropic changes there is no change of weight.

P. Now I think I understand everything.

28. CARBON MONOXIDE.

M. You have seen, several times, what happens when carbon is burned.

P. Yes, a gas is formed named carbon dioxide, which consists of carbon and oxygen. Why is it called dioxide?

M. Because there is another compound of the two elements which is called carbon monoxide. The dioxide

contains twice as much oxygen as the monoxide. The syllables *mon* and *di* are Greek prefixes meaning one and two.

P. What is carbon monoxide like?

M. It is a colourless gas, but differs from the dioxide by being combustible. Moreover, it is very poisonous.

P. Can I see it?

M. Yes, if you can speak of seeing a gas; it is colourless so that you cannot distinguish it from air in appearance; its density and its other physical properties resemble those of nitrogen. But you have often seen it burning.

P. When and where?

M. You have often seen coal burning in the fire. At first you know it gives out a bright flame which comes from the burning of compounds of carbon and hydrogen which resemble coal-gas, and which give the flame its brightness.

P. Yes, of course.

M. After all the coal glows red-hot the flame changes its appearance and becomes pale blue in colour.

P. Yes, I have noticed that. It looks like the flame of a spirit-lamp.

M. Yes, that is the flame of carbon monoxide burning. At first the oxygen of the air combines with the carbon of the coal, to form dioxide; but the dioxide in passing through the red-hot coal combines with the carbon and forms carbon monoxide; then the carbon monoxide burns at the back of the fire to carbon dioxide when it comes in contact with more oxygen.

P. I must look more carefully at that.

M. Do so, and think of this. Carbon monoxide is like nitrogen because it has no smell; but, as I told you, it is very poisonous. If it escapes into the room much

harm may be done, and every year people die of poisoning by carbon monoxide.

P. How does that happen?

M. It seldom happens with an open fire unless the damper in the chimney is shut. But in a stove, if a sufficient quantity of air is not let in to burn the carbon to dioxide, the monoxide is formed, which may escape into the room and poison the people in it.

P. But surely the amount of carbon monoxide in a room must be very small, because the volume of the room is so very much larger than that of the stove, and besides air is always entering through the cracks of the door- and the window-frames.

M. Quite right, but, unfortunately, carbon monoxide is absorbed by the blood even when very little is contained in the air. People who are poisoned by carbon monoxide show no signs of suffocation, but only become dull and sleepy and get headaches, and do not realize what it is and try to escape.

P. Can anything be done with people who are poisoned?

M. The best way is to take them as quickly as possible into the open air, and make them draw deep breaths. If they are far gone oxygen may be given if it is at hand, or artificial respiration may be applied in the same way as for the recovery of the drowning, by moving the arms up and down regularly. Don't forget that coal-gas generally contains a good deal of carbon monoxide, which makes it poisonous. But in general the smell is sufficient warning, although it is due to other constituents of the coal-gas.

P. Isn't it curious that a compound of carbon and oxygen should be poisonous when neither of the elements is poisonous, and when our bodies largely consist of them?

M. No, it is only another example of the fact that the properties of compounds are entirely different from those of their elements. I remember telling you before that it isn't correct to speak as if the elements were *contained* in their compounds.

P. Yes, I remember, too, but it is very difficult to change one's ordinary way of speaking.

29. CARBON DIOXIDE.

M. Do you remember what we have learned about carbon dioxide?

P. Yes, it is formed when charcoal burns, or when any substances containing carbon are burnt. It can be tested for with lime-water.

M. You have remembered that very well. What does the lime-water look like after it has been treated with carbon dioxide?

P. It becomes milky.

M. Yes. In the chemical language we say that a white precipitate is formed.

P. What is precipitated?

M. If you let it stand the milkiness would settle to the bottom as a white layer, for it is heavier than water. A solid substance which is produced in a liquid by a chemical process is called a precipitate. What does carbon dioxide look like?

P. A colourless gas.

M. Yes. It has the peculiar property of being heavier than air and so it behaves in a manner different from hydrogen, for it sinks in air instead of rising like hydrogen.

P. I should like to see that.

M. We must first make some carbon dioxide for that purpose. I shall use a flask exactly like the one I used for making hydrogen (Fig. 24, page 135) only instead of putting zinc in the flask I use chalk or marble; the funnel contains dilute hydrochloric acid. You see that it begins to froth as soon as I let hydrochloric acid into the flask; the gas which is evolved is carbon dioxide.

P. What does the hydrochloric acid do to the chalk?

M. I won't explain that until you know more; but you will soon learn. We shall first make sure that the gas which is evolved is really carbon dioxide. I am passing it into an empty flask, and now I pour in some lime-water and shake it.

P. Yes, I see, that is the white precipitate.

M. This experiment shows you at once that carbon dioxide is heavier than air, for it has stayed in the flask. But I can show you this better by filling two test-tubes with the gas just as we did with hydrogen (page 137) and leaving one with its mouth upwards and the other with its mouth downwards. This time it is the one with its mouth upwards that remains full. How could you find that out?

P. I could test with lime-water.

M. You could do it even more simply. Carbon dioxide puts out a burning splinter. Look, I thrust a burning match up into the tube with its mouth downwards; it goes on burning. But it goes out when I put it into the tube with its mouth upwards.

P. Then the same test does for carbon dioxide as for nitrogen.

M. Yes, so far as the burning splinter is concerned. But they behave differently with lime-water, for nitrogen gives no precipitate with it. It is not uncommon for two

substances to behave similarly towards one test, but if they differ in any respect they must be different substances. There are many other differences between these gases. Carbon dioxide, for instance, is heavier than nitrogen.

P. Why did the splinter go out in carbon dioxide? Doesn't the dioxide contain oxygen?

M. That is a good question. You know the splinter consists largely of carbon; now that carbon would require to displace the carbon in the carbon dioxide, in which it is already combined with oxygen. It is almost as if you were trying to raise yourself into the air.

P. Oh!

M. But other substances can take away oxygen from carbon dioxide. You have seen magnesium ribbon which burns so brightly. I fill a flask with carbon dioxide—

P. Why don't you collect the gas over water?

M. That is not necessary; it is so heavy that it stays at the bottom of the flask. And I know that the flask is full because it puts out a burning spail when I hold it to the mouth; the flask is full, and the carbon dioxide is running over.

P. That's an easy way of doing it! Let me try; yes, now the flask is full.

M. Now I fold several pieces of magnesium ribbon together (for a single piece goes out too easily), light it, and dip it into the carbon dioxide.

P. It hisses and sparkles!

M. You see that it burns quite differently from what it did in the air. There are white and black particles; the white particles are oxide of magnesium, the black particles are the carbon from the carbon dioxide.

P. Oh, may I look at that?

M. Wait a little. I have poured some hydrochloric acid on it; it dissolves the magnesium oxide, and leaves the carbon.

P. Yes, it has become quite black. What made that frothing?

M. It was a little piece of metallic magnesium, which acts like zinc upon the hydrochloric acid, and evolves hydrogen. Now I will show you another property of carbon dioxide. I fill a flask with the gas over water, let a little more water enter, close the mouth with my thumb, and shake. You see my thumb sticks to the mouth, as if it were sucked in; that shows that the pressure in the flask has decreased. When I dip the neck under water and remove my thumb, a good deal of water enters. Now I can repeat this till at last the flask is almost completely filled with water. What does this experiment show us?

P. That carbon dioxide is dissolved in the water.

M. Yes, it is pretty soluble. A litre of water at the ordinary temperature absorbs nearly a litre of carbon dioxide; it absorbs a little more when it is cold, and less when it is warm.

P. Is that not the way soda-water is made? I think I remember your telling me that.

M. Yes, soda-water is a solution of carbon dioxide in water.

P. But doesn't it contain soda?

M. It used to contain soda, but now it is merely a solution of carbonic acid in water. The name carbonic acid, although it is commonly used, should not be applied to the gas, but only to its solution in water. Why does soda-water effervesce? Do you remember what I told you about that?

P. Yes, you told me that the bottles are filled at a high

pressure with the gas, and when they are open the pressure decreases and the gas comes out. I remember, too, that you said that the same volume of gas is dissolved whatever the pressure is.

M. Quite right. You learned that at any given temperature the weights of a gas which fill a given volume are proportional—

P. To the pressures?

M. Yes. If equal volumes are always dissolved at different pressures, what will the weights be proportional to?

P. To the pressures.

M. Quite right. So at different pressures different weights of gas will be dissolved, and these weights are proportional to the pressures. Soda-water has generally a pressure of four atmospheres; therefore it contains four times as much carbon dioxide as it can retain under a pressure of one atmosphere. This excess escapes on opening the bottle, and produces the frothing.

P. Some other liquids foam; for instance, beer. Does that depend upon carbon dioxide, too?

M. Yes, but the gas is not pumped into the beer, but is formed in the beer from malt, and remains dissolved in the liquid.

P. Then where does it come from?

M. There is sugar in malt, and by the action of yeast this is decomposed into alcohol, which gives the beer its intoxicating properties, and into carbon dioxide, some of which is evolved. In beer-cellars they sometimes use iron bottles filled with liquid carbon dioxide for driving the beer out of the casks.

P. Liquid carbon dioxide?

M. Yes, when carbon dioxide is compressed with a powerful pump it turns liquid like water, and indeed has almost the same appearance.

P. It must be a very strong pump.

M. The pressure depends on the temperature. At 0° , 35.4 atmospheres are required; at 20° , 58.8, but at -80° carbon dioxide liquefies at 1 atmosphere pressure. Liquid carbon dioxide boils at -80° . It behaves exactly like water, for its vapour has a higher pressure the higher the temperature. Only the corresponding temperatures for carbon dioxide lie much lower.

P. Should we call carbon dioxide a vapour?

M. You may if you like.

P. Couldn't you bring me some liquid carbon dioxide home in a bottle to see what it is like?

M. That would be impossible, for when it is allowed to escape out of the steel bottle, it becomes solid like snow.

P. How is that?

M. You know that on boiling a liquid, heat is absorbed, all liquids behave in the same way in this respect, and carbon dioxide is no exception. As soon as liquid carbon dioxide is exposed to air which has only one atmosphere pressure, it begins to boil violently, and so much heat is absorbed by the portion which evaporates that the residue freezes.

P. Then it should be possible to freeze water by boiling it! Surely that could never be done!

M. It is not difficult, only care must be taken that the water shall boil below 0° ; and to accomplish that the pressure must be very low. As a matter of fact water can be frozen if it is brought into a space as free from air as possible; and then it behaves exactly as I have told you that carbon dioxide does. Indeed, there are ice machines in which ice can be made in summer by this process. You see carbon dioxide resembles water

in existing in all three forms. Liquid carbon dioxide has become a valuable article of commerce for aerating water and for forcing beer out of casks, and if you look you will often see the steel flasks filled with liquid carbon dioxide being carted about on the streets.

P. Where does it chiefly come from?

M. It pours out of the earth. In many places, especially where there are or have been volcanoes, pure carbon dioxide issues continuously from the soil. When it comes in contact with subterraneous springs, the water becomes saturated with the gas and escapes as carbonated or sparkling water.

P. Why does it taste sour?

M. A solution of carbon dioxide has an acid taste.

P. Is that why it is called carbonic acid?

M. That has to do with it. Sometimes carbon dioxide issues from the earth as a gas, and can be compressed into steel flasks with the help of powerful pumps. There are such carbon dioxide wells at Naples, in the neighbourhood of Vesuvius. There is a cave, the floor of which is somewhat depressed, into which the gas pours until it fills the depression nearly two feet, and the gas flows out over the floor just as if it were water. People can walk about in this grotto without danger, because their heads are above the level of the carbon dioxide, but dogs are suffocated, as they are at a lower level. That is the well-known "Grotto del Cane," or "Cave of the Dog."

P. Do they really let dogs suffocate in it?

M. No, they bring them out before they are dead, and revive them by splashing them with water.

P. How cruel! Why are dogs suffocated by carbon dioxide?

M. For the same reason that they die in nitrogen; because they can get no oxygen to breathe. Carbon dioxide isn't really a poison any more than nitrogen, because it is always present in our lungs.

P. How does it get there?

M. Out of the blood. I have already told you that the food which we eat contains carbon and that it is burnt in our tissues by means of the oxygen which the blood leads to it. It burns to carbon dioxide just as in ordinary combustion; the gas is absorbed by the blood, and we breathe it out from our lungs along with nitrogen.

P. So carbon dioxide is present in the air which I breathe out?

M. Certainly; blow some air through a glass tube into lime-water.

P. So it is, the lime-water becomes milky, and there is a white precipitate. How much I have to think about!

30. THE SUN.

P. I have been puzzling my head ever since the last lesson. I know now that carbon dioxide is produced by combustion, by breathing, and by decay, and that in some places it streams out of the earth. It must all collect in the air, and accumulate. Isn't the air full of carbon dioxide?

M. There is always some in the air, but not very much; only about 4 parts in 10,000. More is present in close rooms when much carbon dioxide has been produced by breathing or by the burning of gas. You can easily recognize it by exposing some lime-water to the air in the room, for it will become covered over with a white scum.

P. Covered over? Oh, I see; because the carbon dioxide can only act on the surface of the water. But what becomes of all the carbon dioxide that is poured into the air? Perhaps the volume of the air is so great that the carbon dioxide makes no difference.

M. That is not the reason. As a matter of fact, there is a state of equilibrium in which the air loses as much carbon dioxide as it receives.

P. What becomes of it then?

M. Plants absorb it. They decompose it in such a manner that the carbon remains in the plant, and helps to form its tissues, while the oxygen is returned to the air as a gas.

P. Can plants really make oxygen? How can I see that?

M. That is not difficult. We take a large glass funnel, fill it with fresh green leaves, and place it upside down in a wide vessel full of fresh water. Then we sink it so deep as to fill it completely with water, and we close the opening with a cork. Then we expose it to sunlight (Fig. 46).

P. Let me help you to lift the pail.

M. You needn't trouble;

I push a plate below the funnel and lift out both together; the water will not run out of the funnel. When the sun shines on it, you see gas bubbles rising, which collect at the top.

P. Isn't that only the gas which has been dissolved in the water, and which escapes when it is heated (page 122)?



FIG. 46.

M. No, the water doesn't grow warm so quickly. We shall leave it standing in the sun till we have collected some cubic centimetres of gas. Then we will put the funnel back in the pail, and hold it so that the water stands at the same level inside and outside; now we can take out the cork, and test for oxygen by means of a glowing spail.

P. That is a beautiful experiment. I shall think of plants quite differently now. What a lot of good they do! I should never have thought it, for, by breathing and burning, all the oxygen in the air would be used up at last. Plants give us it back again.

M. You see that we owe a debt to plants because they not only serve as food, but also because they restore us the oxygen with which we burn our food.

P. I don't quite understand that. I eat as much meat as vegetables.

M. But the animals whose flesh we eat live upon plants. We never eat carnivorous animals. But if we did, these eat graminivorous animals, so that in the long run man and animals are nourished by plants.

P. Yes, I see that. But if plants restore the oxygen to the air, air in the fields and woods must contain much more oxygen. Perhaps that is the reason that the air feels so fresh, and that it is healthy to live in the country.

M. No, that is not the reason. The difference between the amount of oxygen in country air and in town air is very small—it can hardly be detected.

P. How is that? Does it not contradict what you have just told me?

M. The air is in perpetual motion, and it is mixed up so rapidly that the differences quickly disappear. Even a very moderate wind travels a mile in five minutes.

You can think how quickly the air reaches the town from the wood, and *vice versâ*.

P. But above the sea?

M. There is no difference. Not only animals, but also myriads of small plants live in the sea. They all act in the same manner, only they do not decompose the carbon dioxide in the air, but that which is dissolved in the water, and they restore the oxygen in solution. The fishes and other sea animals make use of it, for they too must derive their energy from the combustion of their food.

P. Yes, they breathe through gills. What are gills?

M. They drive the oxygenated water through structures which are permeated with blood-vessels just like the lungs, and in which the carbon dioxide of their tissues is exchanged for oxygen.

P. Just in the same way as with animals that breathe air, except that water takes the place of air.

M. Quite right; and there are still simpler lower animals in which the water penetrates straight into their tissues.

P. It all goes round in a circle; what the animals do not want the plants take up, and what they throw out the animals use. Does the same happen with nitrogen?

M. Yes; only nitrogen, as I have told you, must always remain combined (page 187).

P. I remember; and if the nitrogen becomes free, it is again made to combine in the soil. How wonderful! But tell me one thing; I want to ask you why the leaves must stand in the sun before they give up oxygen?

M. You should be able to answer that yourself. When carbon burns to carbon dioxide, much heat is liberated.

P. Of course, and that is the source of the work done by machines and animals.

M. Then in order to decompose the carbon dioxide again, the same work must be done on it which was liberated when the carbon and oxygen combine. Where do the plants get this work?

P. I haven't thought of that. You said something about the sun; do they get it from the sun?

M. Of course they do. Plants lead a double life. On the one hand they must work exactly like animals. They must pump water, they must grow in size, they must form buds and fruit. They can't make this work out of nothing; they must take it from somewhere by consuming food. Now they differ from animals in this: *they make their own food, and they derive the necessary work or energy from sunlight.*

P. You say that plants derive their energy from food like animals. Then they must give out carbon dioxide?

M. So they do. And that is what their double life consists in. For the work that they carry out as animals they derive the necessary energy from combustion. But they collect this energy from sunlight; indeed they must collect far more than they give out so as to have a reserve for the dark. And so they always evolve carbon dioxide; but that can only be detected in the dark, for in sunlight oxygen is evolved at the same time, and its amount is far more than that of the carbon dioxide.

P. How do plants collect the energy from the sun?

M. We do not know much about that. So far as we know only green plants can do so; colourless plants like fungi and moulds live like animals on plant-food; for example, rich soil, decomposing vegetable matter, and so on. We do not know what becomes of the carbon dioxide in the leaves where the energy is stored up; we

only know that the first product which we can detect is starch. You must look on the green cells of plants as little chemical laboratories, in which are prepared the substances which the plant requires, and which are fitted with arrangements to change sunlight or the radiant energy of the sun into the energy of chemical compounds.

P. Then does our life really depend upon the sun? I remember that you told me (page 180) that the motion of the water and the air on the surface of the earth was caused by the heat of the sun. Really everything which takes place upon the earth appears to depend upon the sun.

M. You are nearly right, for I know only one process which does not; that is the ebb and flow of the tide, which are caused by the attraction of the moon for the sea when the earth revolves. But that is infinitesimally small, compared with the work done by the sun.

P. How does it happen that everything depends on the sun?

M. It happens that the radiation from the sun is the only source of energy that we have at our disposal. As everything that takes place can only take place by the expenditure of work or energy everything depends on the source of the energy.

P. It does not seem so important to pay attention to the elements being formed from their compounds and the compounds being decomposed into elements again as I had thought. It was such a good scheme.

M. It is less important than the stream of energy which is poured from the sun on the earth, and is taken up and stored by plants in order to make life possible. You can make a picture of this by thinking of a mill.

The elements are the wheel which moves in a circle and continually utilizes the work of the falling water. And the falling water represents the rays of the sun, without whose action the mill of life would stop.



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